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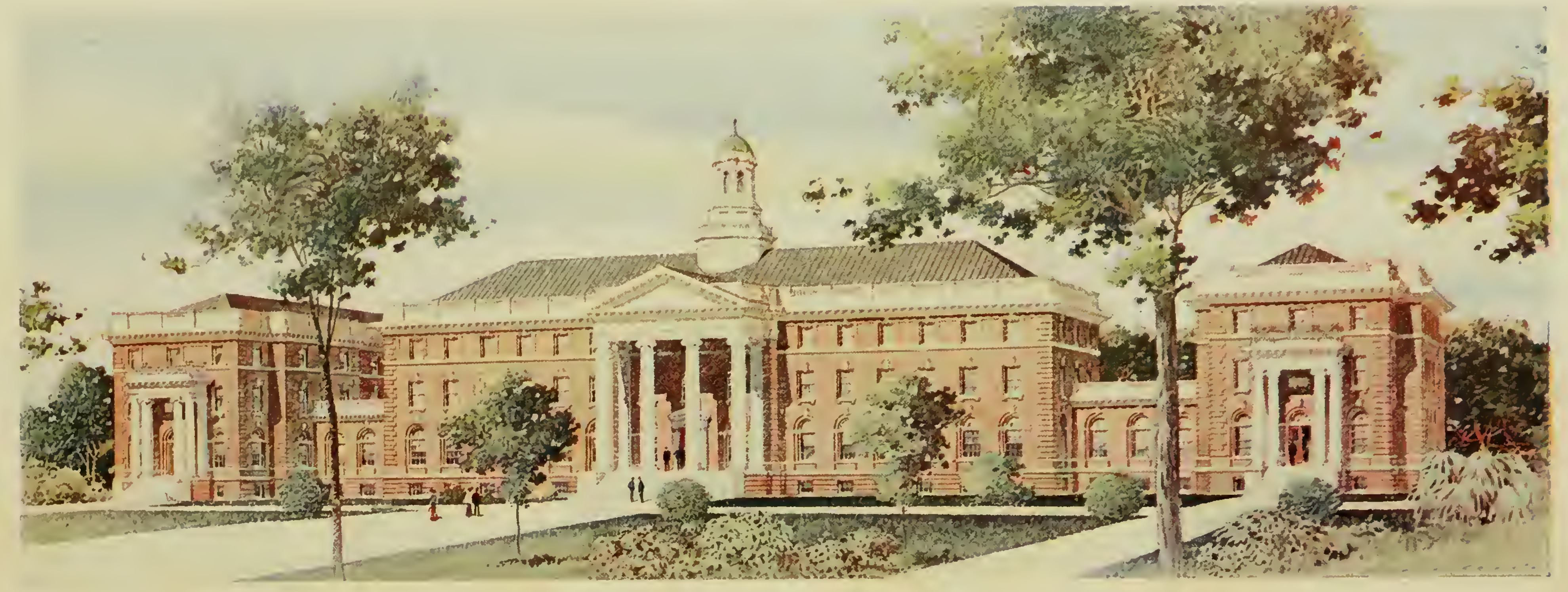

WALTER REED ARMY GENERAL HOSPITAL, WASHINGTON, D. C.
Marsh & Peter, Architects, Washington, D. C.   For plan, see next succeeding plate.

Cyclopedia
of
Architecture, Carpentry and Building

A General Reference Work
ON ARCHITECTURE, CARPENTRY, BUILDING, SUPERINTENDENCE, CONTRACTS, SPECIFICATIONS, BUILDING LAW, STAIR-BUILDING, ESTIMATING, MASONRY, REINFORCED CONCRETE, STEEL CONSTRUCTION, ARCHITECTURAL DRAWING, SHEET METAL WORK, HEATING, VENTILATING, ETC.

Prepared by a Staff of
ARCHITECTS, BUILDERS, AND EXPERTS OF THE HIGHEST PROFESSIONAL STANDING

Illustrated with over Three Thousand Engravings

TEN VOLUMES

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THE editors have freely consulted the standard technical literature of America and Europe in the preparation of these volumes. They desire to express their indebtedness particularly to the following eminent authorities whose well-known works should be in the library of everyone connected with building.

Grateful acknowledgment is here made also for the invaluable cooperation of the foremost architects, engineers, and builders in making these volumes thoroughly representative of the very best and latest practice in the design and construction of buildings; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

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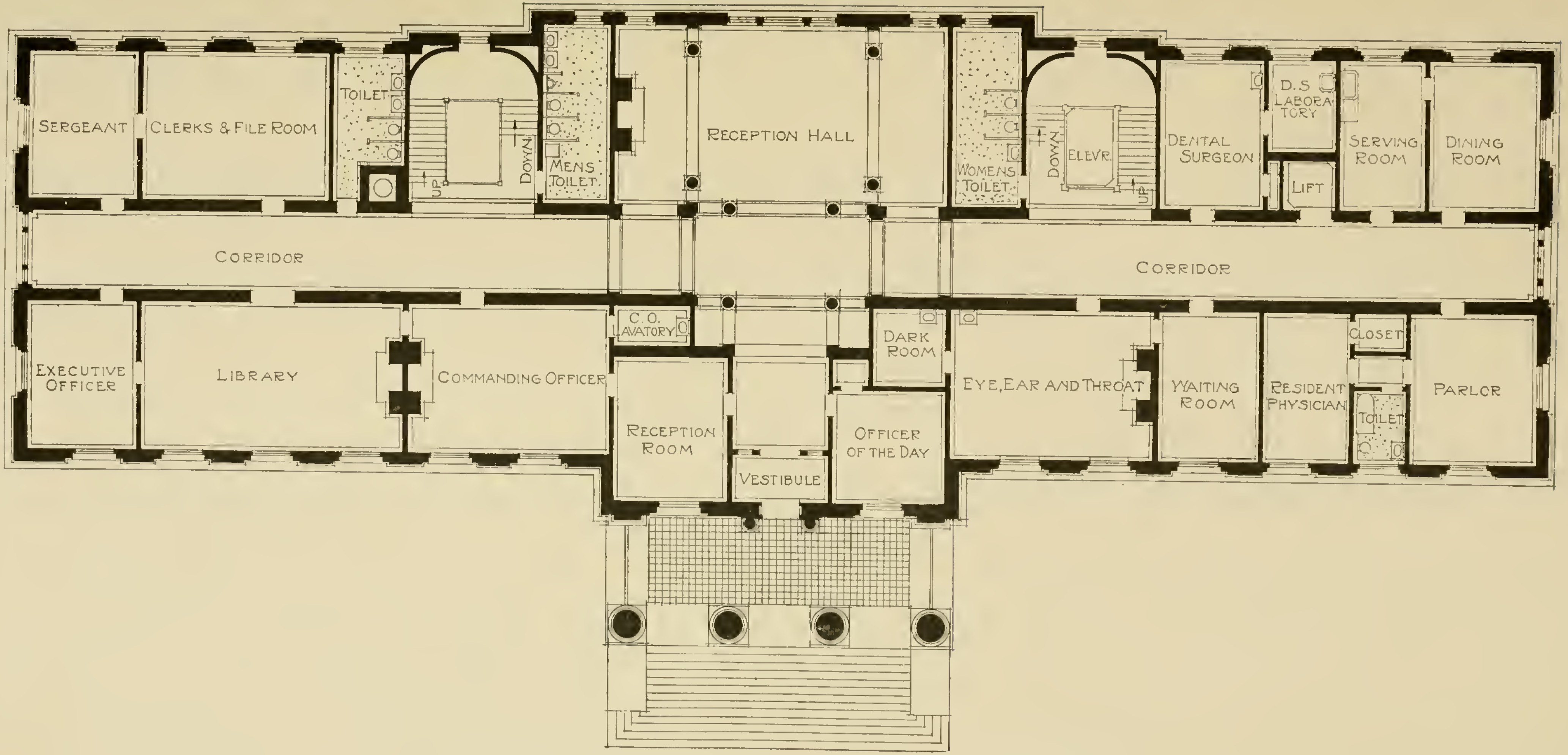

PLAN OF WALTER REED ARMY GENERAL HOSPITAL, WASHINGTON, D. C.

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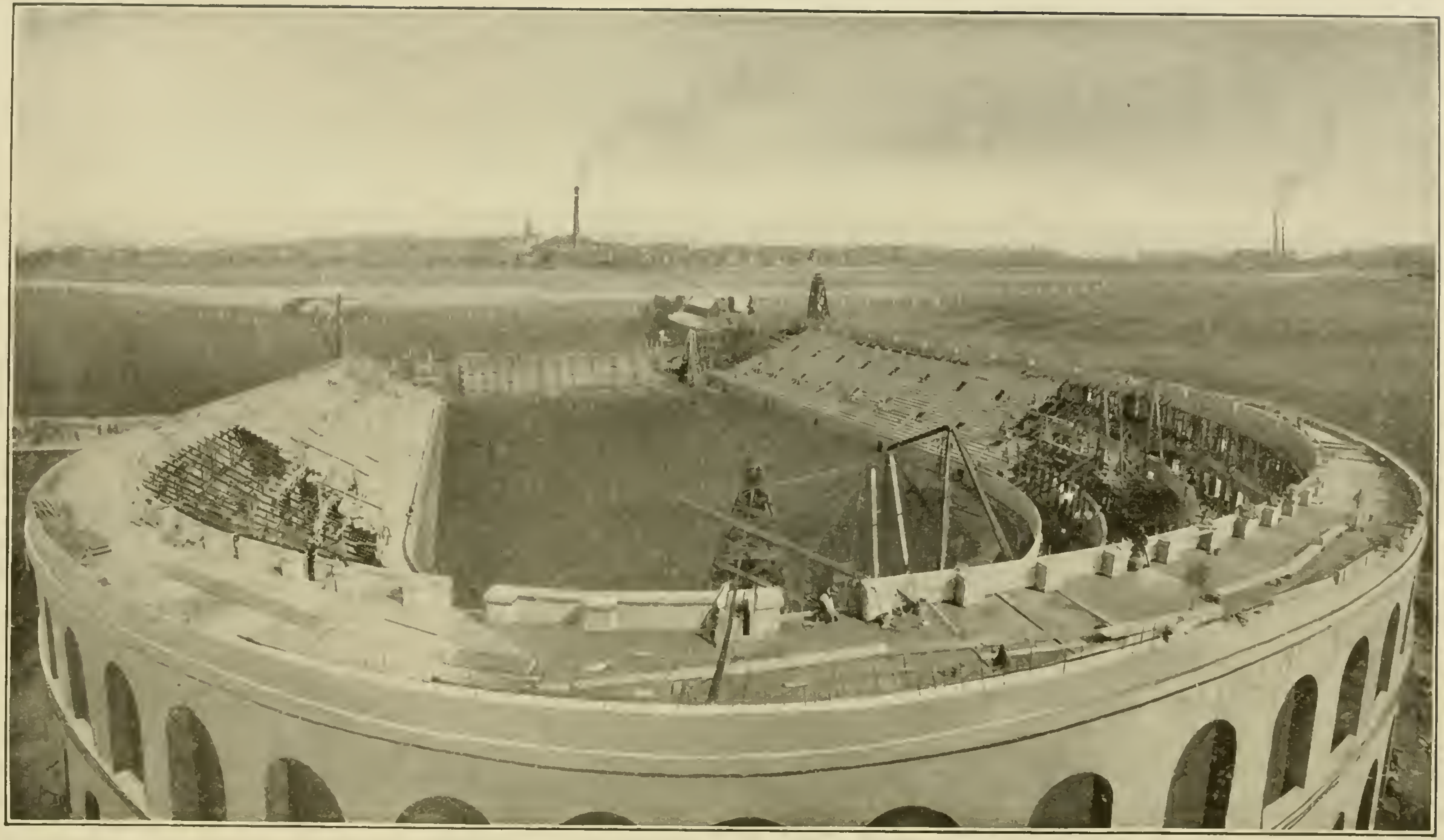

STADIUM AT HARVARD UNIVERSITY, CAMBRIDGE, MASS.

Built entirely of Reinforced Concrete.

Reproduced by Courtesy of John Wiley & Sons, from "A Treatise on Concrete, Plain and Reinforced," by Frederick W. Taylor, M. E., and Sanford E. Thompson, S. B.

Foreword

THE rapid evolution of constructive methods in recent years, as illustrated in the use of steel and concrete, and the increased size and complexity of buildings, has created the necessity for an authority which shall embody accumulated experience and approved practice along a variety of correlated lines. The Cyclopedia of Architecture, Carpentry, and Building is designed to fill this acknowledged need.

❡ There is no industry that compares with Building in the close interdependence of its subsidiary trades. The Architect, for example, who knows nothing of Steel or Concrete construction is to-day as much out of place on important work as the Contractor who cannot make intelligent estimates, or who understands nothing of his legal rights and responsibilities. A carpenter must now know something of Masonry, Electric Wiring, and, in fact, all other trades employed in the erection of a building; and the same is true of all the craftsmen whose handiwork will enter into the completed structure.

❡ Neither pains nor expense have been spared to make the present work the most comprehensive and authoritative on the subject of Building and its allied industries. The aim has been, not merely to create a work which will appeal to the trained expert, but one that will commend itself also to the beginner and the self-taught, practical man by giving him a working knowledge of the principles and methods, not only of his own particular trade, but of all other branches of the Building Industry as well. The various sections have been prepared especially for home study, each written by an acknowledged authority on the subject. The arrangement of matter is such as to carry the student forward by easy stages. Series of review questions are inserted in each volume, enabling the reader to test his knowledge and make it a permanent possession. The illustrations have been selected with unusual care to elucidate the text.

¶ The work will be found to cover many important topics on which little information has heretofore been available. This is especially apparent in such sections as those on Steel, Concrete, and Reinforced Concrete Construction; Building Superintendence; Estimating; Contracts and Specifications, including the principles and methods of awarding and executing Government contracts; and Building Law.

¶ The Cyclopedia is a compilation of many of the most valuable Instruction Papers of the American School of Correspondence, and the method adopted in its preparation is that which this School has developed and employed so successfully for many years. This method is not an experiment, but has stood the severest of all tests—that of practical use—which has demonstrated it to be the best yet devised for the education of the busy working man.

¶ In conclusion, grateful acknowledgment is due the staff of authors and collaborators, without whose hearty co-operation this work would have been impossible.

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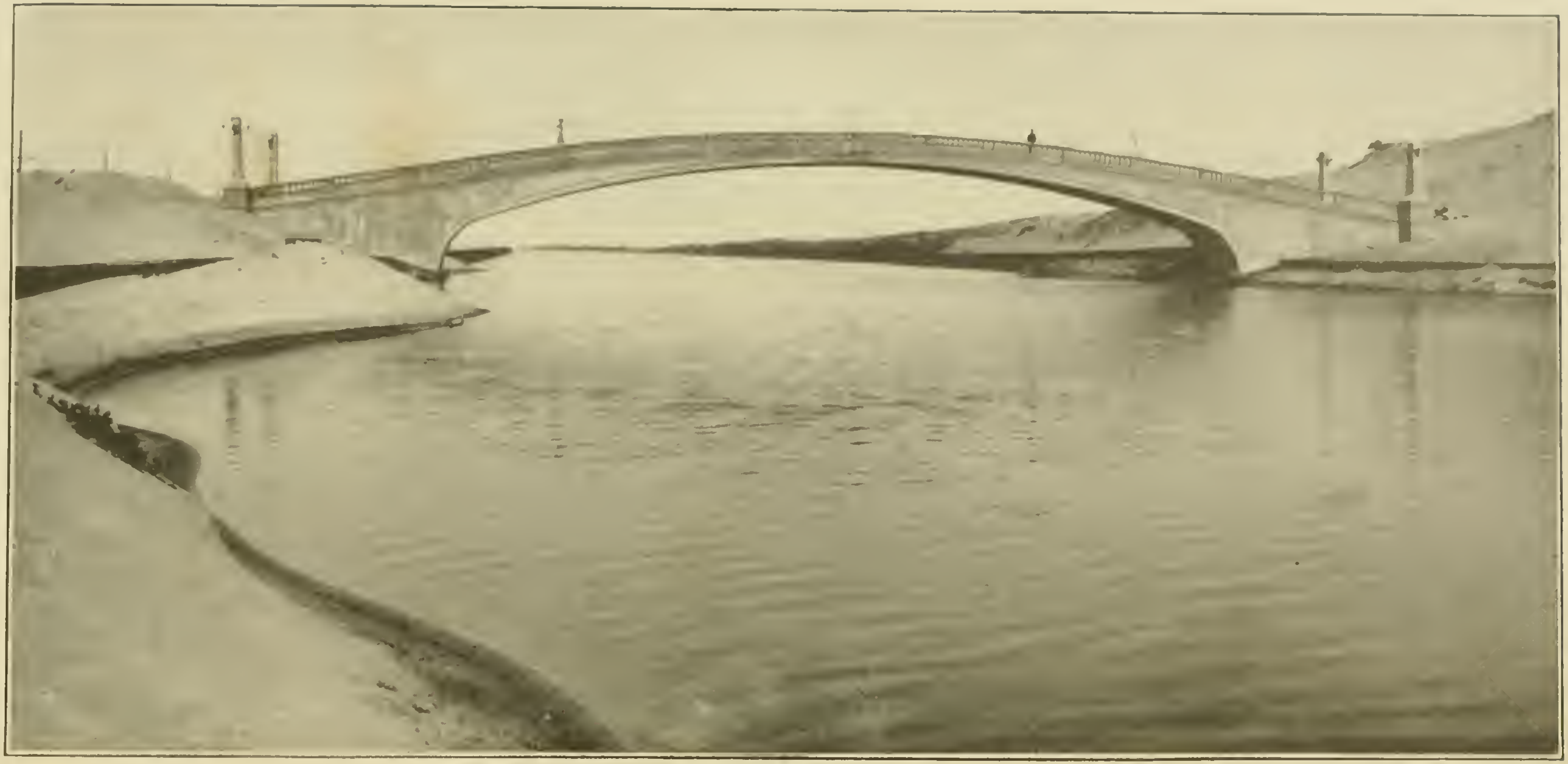


BRIDGE OF REINFORCED CONCRETE, AT PLAYA DEL REY, NEAR LOS ANGELES, CAL.

Extreme Length, 205 feet 8 inches; Span, 146 feet; Width, 19 feet; Spring, 18 feet; Height above water, 20 feet.

REINFORCED CONCRETE

PART I

CEMENT

The discussion of cementing materials will here be confined to Portland cement. A treatise on masonry will usually include a discussion of the various forms of lime and other cementing materials. These are cheaper and sometimes justifiably economical in large masses of masonry. There is hardly an exception to the general statement that Portland cement is the only form of cementing material which should be used in reinforced concrete.

Characteristics of Portland Cement. The value of cement as a building material depends on the following general qualities. When mixed with water and allowed to set, it should harden in a few hours and should develop a considerable proportion of its ultimate strength in a few days. It must also have the characteristic of permanency so that no material change in form or volume will take place on account of inherent qualities or as the result of exterior agencies. There always is a slight shrinkage of the volume of cement and concrete during the process of setting and hardening, but with any good quality of cement this shrinkage is not so great as to be objectionable. Another very essential quality is that the cement shall not lose its strength with age. Although some long-time tests of cement have apparently indicated a slight decrease in the strength of cement after the first year, the decrease is so slight that it need not affect the design of concrete, even assuming the accuracy of the general statement.

CEMENT TESTING

The thorough testing of cement, as it is done for the largest public works, should properly be done in a professional testing laboratory. A text-book of several hundred pages has recently been written on this subject. The ultimate analysis and testing of cement, both chemically and physically, is beyond the province of the ordinary engineer. But the ordinary engineer does have frequent occasion to obtain cement in small quantities when testing in professional laboratories is inconvenient or unduly expensive. Fortunately it is possible to make some simple tests without elaborate apparatus which will at least show whether the cement is radically defective and unfit for use. It is unfortunately true that an occasional barrel of even the best brand of cement will prove to be very inferior to the standard output of that brand. This practically means that in any important work, using a large quantity of cement, it is not sufficient to choose a brand, as the result of preliminary favorable tests, and then accept all shipments without further test. Several barrels in every carload should be sampled for testing. It is not too much to prescribe that *every* barrel should be tested by at least a few of the simpler forms of testing given below. The following methods of testing are condensed from the progress report of the Committee on Uniform Tests of Cement, as selected by the American Society of Civil Engineers. The statements may therefore be considered as having the highest authority obtainable on this subject.

Sampling. The number of samples that should be taken depends on the importance of the work but it is chiefly important that the sample should represent a fair average of the contents. The sample should be passed through a sieve having twenty meshes per linear inch, in order to break up lumps and remove any foreign material. If several small amounts are taken from different parts of the package, this also insures that the samples will be mixed so that the result will be a fair average. When it is only desired to determine the average characteristic of a shipment, the samples taken from different parts of the shipment may be mixed, but it will give a better idea of the uniformity of the product to analyze the different samples separately. Cement should be taken from a barrel by boring a hole through the center of one of the staves, midway between the heads, or through the head. A portion of the cement can then be withdrawn, even from the center, by means of a sampling iron similar to that used by sugar inspectors.

Chemical Analysis. Ordinarily, it is impracticable for an engineer to make a chemical analysis of cement which will furnish reliable information regarding its desirability, but the engineer should understand something regarding the desirable chemical constituents of the cement. It should be realized that the fineness of the grinding and the thoroughness of the burning may have a far greater influence on the value of the cement than slight variations from the recognized standard proportions of the various chemical constituents. Too high a proportion of lime will cause failure in the test for soundness or constancy of volume, although a cement may fail on such a test owing to improper preparation of the raw material or defective burning. On the other hand, if the cement is made from very finely ground material and is thoroughly burned, it may contain a considerable excess of lime and still prove perfectly sound. The permissible amount of magnesia in Portland cement is the subject of considerable controversy. Some authorities say that anything in excess of 8 per cent is harmful, others declare that the amount should not exceed 4 per cent or 5 per cent. The proportion of sulphuric-anhydride should not exceed 1.75 per cent. It may be considered that the other tests of cement are a far more reliable indication of its quality than any small variation in the chemical constituents from the proportions usually considered standard.

Specific Gravity. The specific gravity of cement is lowered by *under-burning, adulteration,* and *hydration,* but the adulteration must be in considerable quantities to affect the results. Since the differences in specific gravity are usually very small, great care must be exercised in making the tests. When properly made, the tests afford a quick check for under-burning or adulteration. The determination of specific gravity is conveniently made with Le Chatelier's apparatus. This consists of a flask D, Fig. 1, of 120-cu. cm. (7.32-cu. in.) capacity, the neck of which is about 20 cm. (7.87 in.) long; in the middle of this neck is a ball C, above and below which are two marks F and E; the volume between these marks is 20 cu. cm. (1.22 cu. in.). The neck has a diameter of about 9 mm. (0.35 in.), and is graduated into tenths of cu. cm. above the mark F. Benzine (62° Baumé naphtha), or kerosene free from water, should be used in making the determination.

The specific gravity may be determined in two ways:

First. The flask is filled with either of these liquids to the lower mark E, and 64 gr. (2.25 oz.) of powder, previously dried at 100° Cent. (212° Fahr.) and cooled to the temperature of the liquid, is gradually introduced through the funnel B (the stem of which extends into the flask to the top of the bulb C) until the proper mark F is reached. The difference in weight between the cement remaining and the original quantity (64 gr.) is the weight which has displaced 20 cu. cm.

Second. The whole quantity of powder is introduced, and the level of the liquid rises to some division of the graduated neck. This reading plus 20 cu. cm. is the volume displaced by 64 gr. of the powder. The specific gravity is then obtained from the formula:

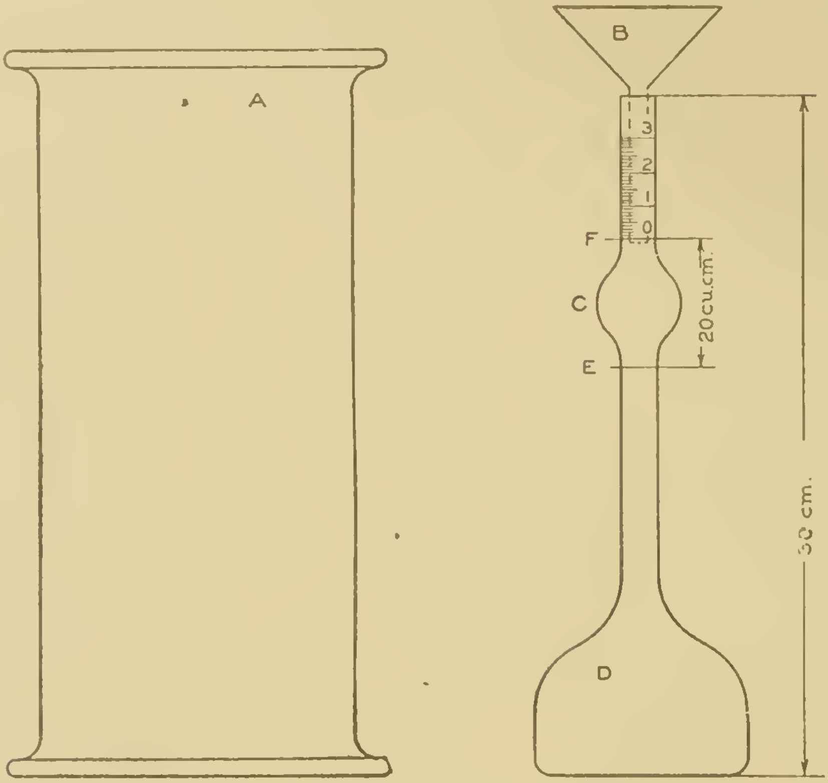


Fig. 1. Le Chatelier's Apparatus for Determining Specific Gravity.

$$\text{Specific Gravity} = \frac{\text{Weight of cement}}{\text{Displaced volume}}.$$

The flask during the operation is kept in water in a jar A in order to avoid variation in the temperature of the liquid. The results should agree within 0.01. The specific gravity of cement thoroughly dried at 100° Cent. should not be less than 3.10.

Fineness. It is generally accepted that the coarser materials in cement are practically inert, and it is only the extremely fine powder that possesses adhesive cementing qualities. The more finely cement is pulverized, all other conditions being the same, the more sand it will carry and produce a mortar of a given strength. The degree of pulverization which the cement receives at the place of manufacture is ascertained by measuring the residue retained on certain sieves. Those known as No. 100 and No. 200 sieves are recommended for this purpose. The sieve should be circular, about 20 cm. (7.87 inches) in diameter, 6 cm. (2.36 inches) high, and provided with a pan 5 cm. (1.97 inches) deep, and a cover. The wire cloth should be woven from brass wire having the following diameters: No. 100, 0.0045 inches; No. 200, 0.0024 inches. This cloth should be mounted on the frame without distortion. The mesh should be regular in spacing and be within the following limits:

No. 100, 96 to 100 meshes to the linear inch.
No. 200, 188 to 200 meshes to the linear inch.

50 grams (1.76 oz.) or 100 gr. (3.52 oz.) should be used for the test and dried at a temperature of 100° Cent. or 212° Fahr., prior to sieving.

The thoroughly dried and coarsely screened sample is weighed and placed on the No. 200 sieve, which, with pan and cover attached, is held in one hand in a slightly inclined position, and moved forward and backward, at the same time striking the side gently with the palm of the other hand, at the rate of about 200 strokes per minute. The operation is continued until not more than $\frac{1}{10}$ of 1 per cent passes through after one minute of continuous sieving. The residue is weighed, then placed on the No. 100 sieve and the operation repeated. The work may be expedited by placing in the sieve a small quantity of large shot. The results should be reported to the nearest tenth of 1 per cent.

It shall leave by weight a residue of not more than 8 per cent on the No. 100, and not more than 25 per cent on the No. 200 sieve.

Normal Consistency. The use of a proper percentage of water in making the pastes, cement and water, from which pats, tests of setting, and briquettes are made, is exceedingly important, and affects vitally the results obtained. The determination consists in measuring the amount of water required to reduce the cement to a given state of plasticity, or to what is usually designated the normal consistency.

Various methods have been proposed for making this determination, none of which has been found entirely satisfactory. The Committee recommends the following:

The apparatus for this test consists of a frame K, Fig. 2, bearing a movable rod L, with the cap A at one end, and at the other the cylinder B, 1 cm. (0.39 in.) in diameter, the cap, rod, and cylinder weighing 300 gr. (10.58 oz.). The rod, which can be held in any desired position by a screw F, carries an indicator, which moves over a scale (graduated to centimeters) attached to the frame K. The paste is held by a conical, hard-rubber ring I, 7 cm. (2.76 in.) in diameter at the base, 4 cm. (1.57 in.) high, resting on a glass plate J about 10 cm. (3.94 in. square).

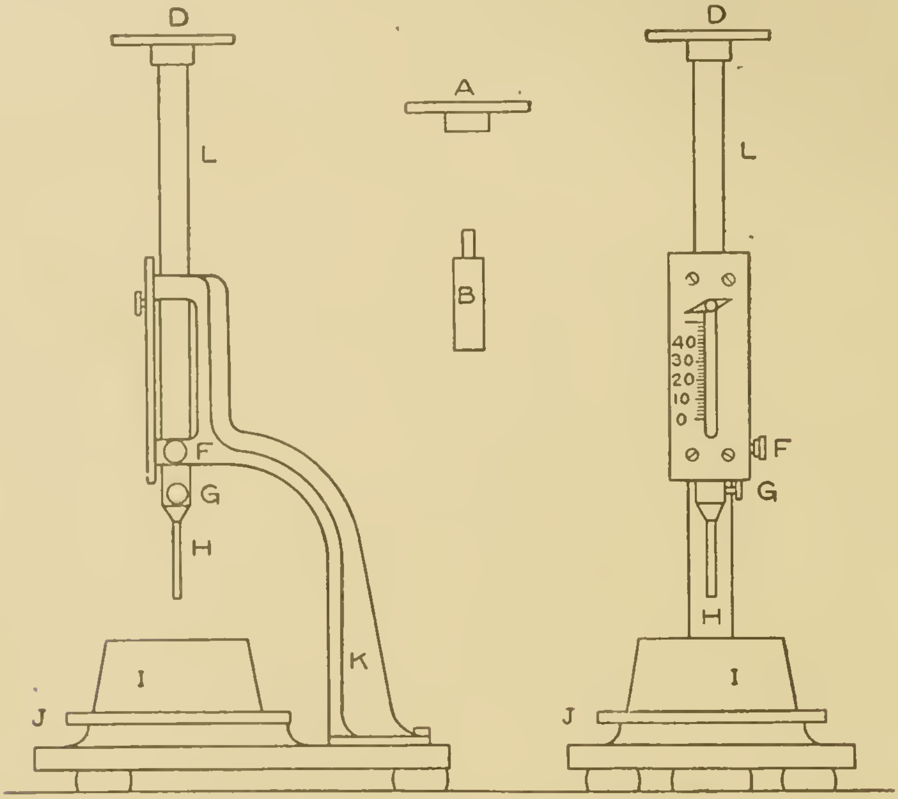


Fig. 2. Apparatus for Testing Normal Consistency of Cement.

In making the determination, the same quantity of cement as will be subsequently used for each batch in making the briquettes (but not less than 500 grams) is kneaded into a paste, as described later in paragraph on "Mixing," and quickly formed into a ball with the hands, completing the operation by tossing it six times from one hand to the other, maintained 6 inches apart; the ball is then pressed into the rubber ring, through the larger opening, smoothed off, and placed (on its large end) on a glass plate and the smaller end smoothed off with a trowel; the paste confined in the ring, resting on the plate, is placed under the rod bearing the cylinder, which is brought in contact with the surface and quickly released.

The paste is of normal consistency when the cylinder penetrates to a point in the mass 10 mm. (0.39 in.) below the top of the ring. Great care must be taken to fill the ring exactly to the top. The trial pastes are made with varying percentages of water until the correct consistency is obtained. The Committee has recommended, as normal, a paste the consistency of which is rather wet, because it believes that variations in the amount of compression to which the briquette is subjected in moulding are likely to be less with such a paste. Having determined in this manner the proper percentage of water required to produce a paste of normal consistency, the proper percentage required for the mortars is obtained from an empirical formula. The Committee hopes to devise a formula. The subject proves to be a very difficult one, and, although the Committee has given it much study, it is not yet prepared to make a definite recommendation.

Note. The Committee on Standard Specifications for Cement inserts the following table for temporary use to be replaced by one to be devised by the Committee of the American Society of Civil Engineers.

TABLE I

Percentage of Water for Standard Sand Mortars

PERCENTAGE OF WATER FOR NEAT CEMENT	ONE CEMENT THREE STANDARD OTTAWA SAND	PERCENTAGE OF WATER FOR NEAT CEMENT	ONE CEMENT THREE STANDARD OTTAWA SAND	PERCENTAGE OF WATER FOR NEAT CEMENT	ONE CEMENT THREE STANDARD OTTAWA SAND
15	8.0	23	9.3	31	10.7
16	8.2	24	9.5	32	10.8
17	8.3	25	9.7	33	11.0
18	8.5	26	9.8	34	11.2
19	8.7	27	10.0	35	11.5
20	8.8	28	10.2	36	11.5
21	9.0	29	10.3	37	11.7
22	9.2	30	10.5	38	11.8
	1 to 1	1 to 2	1 to 3	1 to 4	1 to 5
Cement.....	500	333	250	200	167
Sand	500	666	750	800	833

Time of Setting. The object of this test is to determine the time which elapsed from the moment water is added until the paste ceases to be fluid and plastic (called the "initial set"), and also the time required for it to acquire a certain degree of hardness (called the "final" or "hard set"). The former of these is the more important, since, with the commencement of setting, the process of crystallization or hardening is said to begin. As a disturbance of this process may produce a loss of strength, it is desirable to complete the operation of mixing and moulding or incorporating the mortar into the work before the cement begins to set. It is usual to measure arbitrarily the beginning and end of the setting by the penetration of weighted wires of given diameters.

For this purpose the Vicat Needle, which has already been described, should be used. In making the test, a paste of normal consistency is moulded and placed under the rod L, Fig. 2, as described in a previous paragraph. This rod bears the cap D at one end and the needle H, 1 mm. (0.039 in.) in diameter, at the other, and weighs 300 gr. (10.58 oz.). The needle is then carefully brought in contact with the surface of the paste and quickly released. The setting is said to have commenced when the needle ceases to pass a point 5 mm. (0.20 in.) above the upper surface of the glass plate, and is said to have terminated the moment the needle does not sink visibly into the mass.

The test pieces should be stored in moist air during the test; this is accomplished by placing them on a rack over water contained in a pan and covered with a damp cloth, the cloth to be kept away from them by means of a wire screen; or they may be stored in a moist box or closet. Care should be taken to keep the needle clean, as the collection of cement on the sides of the needle retards the penetration, while cement on the point reduces the area and tends to increase the penetration. The determination of the time of setting is only approximate, being materially affected by the temperature of the mixing water, the temperature and humidity of the air during the test, the percentage of water used, and the amount of moulding the paste receives.

The following approximate method, not requiring the use of apparatus, is sometimes used, although not referred to by the Committee. Spread cement paste of the proper consistency on a piece of glass, having the cement cake about three inches in diameter and about one inch thick at the center, thinning towards the edges. When the cake is hard enough to bear a gentle pressure of the finger nail, the cement has begun to set, and when it is not indented by a considerable pressure of the thumb nail, it is said to have set.

The Committee recommends that it shall develop initial set in not less than thirty minutes, but must develop hard set in not less than one hour, nor more than ten hours.

Standard Sand. The Committee recognizes the grave objections to the standard quartz now generally used, especially on account of its high percentage of voids, the difficulty of compacting in the moulds, and its lack of uniformity; it has spent much time in investigating the various natural sands which appeared to be available and suitable for use. For the present, the Committee recommends the natural sand from Ottawa, Ill., screened to pass a sieve having 20 meshes per linear inch and retained on a sieve having 30 meshes per linear inch; the wires to have diameters of 0.0165 and 0.0112 inches, respectively, i.e., half the width of the opening in each case. Sand having passed the No. 20 sieve shall be considered standard when

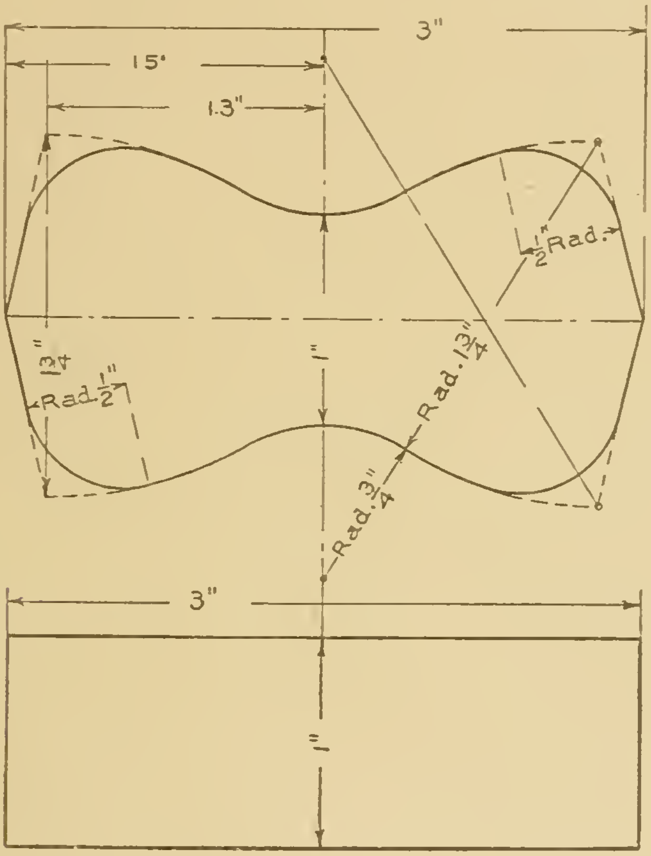


Fig. 3. Form of Briquette.

not more than one per cent passes a No. 30 sieve after one minute continuous sifting of a 500-gram sample.

Form of Briquette. While the form of the briquette recommended by a former Committee of the Society is not wholly satisfactory, this Committee is not prepared to suggest any change, other than rounding off the corners by curves of ½-inch radius, Fig. 3.

Moulds. The moulds should be made of brass, bronze, or some equally non-corrodible material, having sufficient metal in the sides to prevent spreading during moulding.

Gang moulds, which permit moulding a number of briquettes at one time, are preferred by many to single moulds; since the greater quantity of mortar that can be mixed tends to produce greater uniformity in the results. The type shown in Fig. 4 is recommended. The moulds should be wiped with an oily cloth before using.

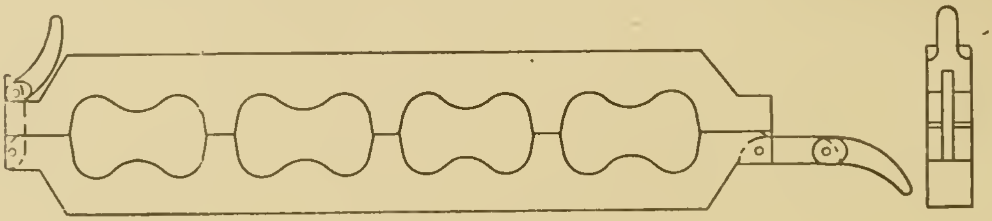


Fig. 4. Gang Moulds.

Mixing. All proportions should be stated by weight; the quantity of water to be used should be stated as a percentage of the dry material. The metric system is recommended because of the convenient relation of the gram and the cubic centimeter. The temperature of the room and the mixing water should be as near 21° Cent. (70° Fahr.) as it is practicable to maintain it. The sand and cement should be thoroughly mixed dry. The mixing should be done on some non-absorbing surface, preferably plate glass. If the mixing must be done on an absorbing surface it should be thoroughly dampened prior to use. The quantity of material to be mixed at one time depends on the number of test pieces to be made; about 1000 gr. (35.28 oz.) makes a convenient quantity to mix, especially by hand methods.

The material is weighed and placed on the mixing table, and a crater formed in the center, into which the proper percentage of clean water is poured; the material on the outer edge is turned into the crater by the aid of a trowel. As soon as the water has been absorbed, which should not require more than one minute, the operation is completed by vigorously kneading with the hands for an additional $1\frac{1}{2}$ minutes, the process being similar to that used in kneading dough. A sand-glass affords a convenient guide for the time of kneading. During the operation of mixing the hands should be protected by gloves, preferably of rubber.

Moulding. Having worked the paste or mortar to the proper consistency, it is at once placed in the moulds by hand. The moulds should be filled at once, the material pressed in firmly with the fingers and smoothed off with a trowel without ramming; the material should be heaped up on the upper surface of the mould, and, in smoothing off, the trowel should be drawn over the mould in such a manner as to exert a moderate pressure on the excess material. The mould should be turned over and the operation repeated. A check upon the uniformity of the mixing and moulding is afforded by weighing the briquettes just prior to immersion, or upon removal from the moist closet. Briquettes which vary in weight more than 3 per cent from the average should not be tested.

Storage of the Test Pieces. During the first 24 hours after moulding, the test pieces should be kept in moist air to prevent them from drying out. A moist closet or chamber is so easily devised that the use of the damp cloth should be abandoned if possible. Covering the test pieces with a damp cloth is objectionable, as commonly used, because the cloth may dry out unequally, and, in consequence, the test pieces are not all maintained under the same condition. Where a moist closet is not available, a cloth may be used and kept uniformly wet by immersing the ends in water. It should be kept from direct contact with the test pieces by means of a wire screen or some similar arrangement.

A moist closet consists of a soapstone or slate box, or a metal-lined wooden box: the metal lining being covered with felt and this felt kept wet. The bottom of the box is so constructed as to hold water, and the sides are provided with cleats for holding glass shelves on which to place the briquettes. Care should be taken to keep the air in the closet uniformly moist. After 24 hours in moist air the test pieces for longer periods of time should be immersed in water maintained as near 21° Cent. (70° Fahr.) as practicable; they may be stored in tanks or pans, which should be of non-corrodible material.

Tensile strength. The tests may be made on any standard machine. A solid metal clip, as shown in Fig. 5, is recommended. This clip is to be used without cushioning at the points of contact with the test specimen. The bearing at each point of contact should be $\frac{1}{4}$-inch wide, and the distance between the center of contact on the same clip should be $1\frac{1}{4}$ inches. Test pieces should be broken as soon as they are removed from the water. Care should be observed in centering the briquettes in the testing machine, as cross-strains, produced by improper centering, tend to lower the breaking strength. The load should not be applied too suddenly, as it may produce vibration, the shock from which often breaks the briquette before the ultimate strength is reached. Care must be taken that the clips and the sides of the briquette be clean and free from grains of sand or dirt, which would prevent a good bearing. The load should be applied at the rate of 600 lbs. per minute. The average of the briquettes of each sample tested should be taken as the test, excluding any results which are manifestly faulty.

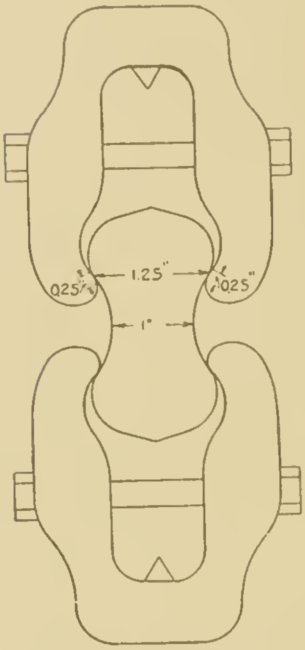


Fig. 5. Metal Clip for Testing Tensile Strength.

The minimum requirements for tensile strength for briquettes one inch square in section shall be within the following limits, and shall show no retrogression in strength within the periods specified:

MINIMUM STRENGTH OF BRIQUETTES

Age	Strength
NEAT CEMENT	
24 hours in moist air	150-200 lbs.
7 days (1 day in moist air, 6 days in water)	450-550 "
28 days (1 day in moist air, 27 days in water)	550-650 "
ONE PART CEMENT, THREE PARTS SAND	
7 days (1 day in moist air, 6 days in water)	150-200 "
28 days (1 day in moist air, 27 days in water)	200-300 "

Constancy of Volume. The object is to develop those qualities which tend to destroy the strength and durability of a cement. As it is highly essential to determine such qualities at once, tests of this character are for the most part made in a very short time, and are known, therefore, as accelerated tests. Failure is revealed by cracking, checking, swelling, or disintegration, or all of these phenomena. A cement which remains perfectly sound is said to be of constant volume.

Methods. Tests for constancy of volume are divided into two classes:

(1) Normal tests, or those made in either air or water maintained at about 21° Cent. (70° Fahr.).

(2) Accelerated tests, or those made in air, steam, or water at a temperature of 45° Cent. (115° Fahr.) and upward. The test pieces should be allowed to remain 24 hours in moist air before immersion in water or steam, or preservation in air. For these tests, pats, about $7\frac{1}{2}$ cm. (2.95 in.) in diameter, $1\frac{1}{4}$ cm. (0.49 in.) thick at the center, and tapering to a thin edge, should be made, upon a clean glass plate [about 10 cm. (3.94 in.) square], from cement paste of normal consistency.

Normal Test. A pat is immersed in water maintained as near 21° Cent. (70° Fahr.) as possible for 28 days, and observed at intervals. A similar pat is maintained in air at ordinary temperature and observed at intervals.

Accelerated Test. A pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel, for 3 hours.

To pass these tests satisfactorily, the pats should remain firm and hard, and show no signs of cracking, distortion, or disintegration. Should the pat leave the plate, distortion may be detected best with a straight-edge applied to the surface which was in contact with the plate. In the present state of our knowledge it cannot be said that cement should necessarily be condemned simply for failure to pass the accelerated tests; nor can a cement be considered entirely satisfactory, simply because it has passed these tests.

Testing Machines. There are many varieties of testing machines on the market. Many engineers have constructed "home-made" machines which serve their purpose with sufficient accuracy. One very common type of machine is illustrated in Fig. 6. B is a reservoir containing shot which falls through the pipe I which is closed with a valve at the bottom. The briquette is carefully placed between the clips, as shown in the figure, and the wheel P is turned until the indicators are in line. The hook lever Y is moved so that a screw worm is engaged with its gear. Then open the automatic valve J so as to allow the shot to run into the cup F. By means of a small valve the flow of shot into the cup may be regulated. Better results will be obtained by allowing the shot to run slowly into the cup. The crank is then turned with just sufficient speed so that the scale beam is held in position until the briquette is broken. Upon the breaking of the briquette, the scale beam falls and automatically closes the valve J. The weight of the shot in the cup F then indicates, according to some definite ratio, the stress required to break the briquette.

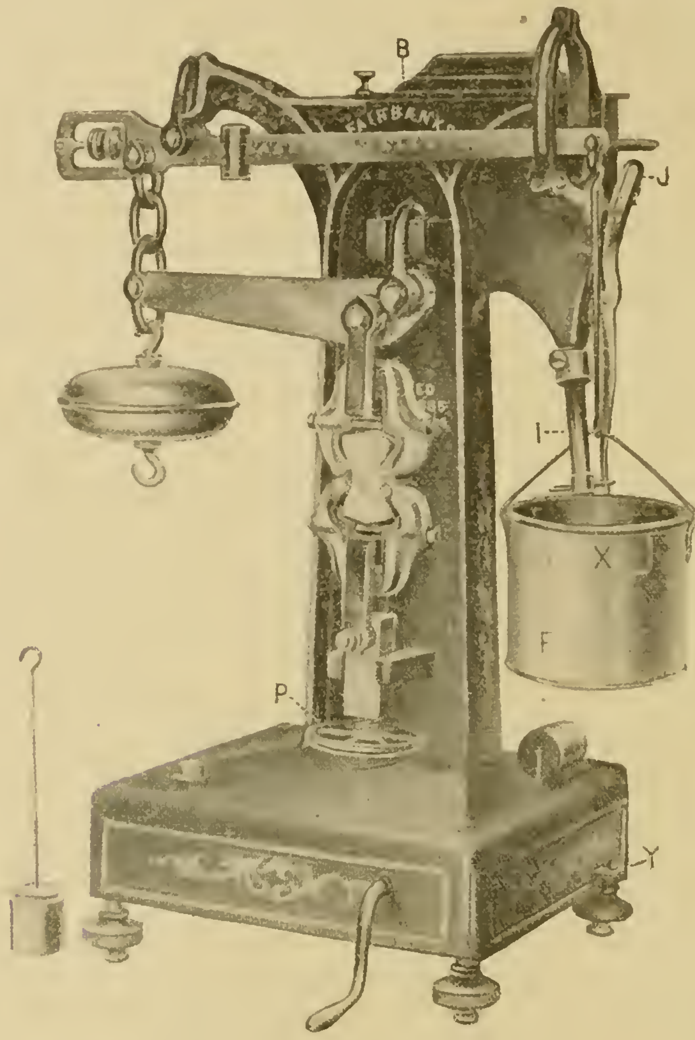


Fig. 6. Cement Testing Machine.

Sand. Specifications for concrete usually state that the sand shall be clean, coarse, and sharp; free from clay, loam, sticks, organic matter, or other impurities. A mixture of coarse and fine grains, with the coarse grains predominating, is found very satisfactory as it makes a denser and stronger concrete with a less amount of cement than when coarse-grained sand is used with the same proportion of cement. The small grains of sand fill the voids caused by the coarse grains so that there is not as great a volume of voids to be filled by the cement. The sharpness of sand can be determined approximately by rubbing a few grains in the hand or by crushing it near the ear and noting if a grating sound is produced; but an examination through a small lens is better.

Experiments have shown that round grains of sand have less voids than angular ones, and that water-worn sands have from 3 per cent to 5 per cent less voids than corresponding sharp grains. In many parts of the country where it is impossible, except at a great expense, to obtain the sharp sand, the rounded grain is used with very good results. Laboratory tests made under conditions as nearly as possible identical show that the rounded-grain sand gives as good results as the sharp sand. In consequence of such tests, the requirement that sand shall be *sharp* is now considered useless by many engineers, especially when it leads to additional cost.

In all specifications for concrete work is found the clause that "the sand shall be clean." This requirement is sometimes questioned as experimenters have found that a small percentage of clay or loam often gives better results than when clean sand is used. "Lean" mortar may be improved by a small percentage of clay or loam, or by using dirty sand, for the fine material increases the density. In rich mortars this fine material is not needed, as the cement furnishes all the fine material necessary, and if clay or loam or dirty sand were used it might prove detrimental. Whether it is really a benefit or not depends chiefly upon the richness of the concrete and the coarseness of the sand. Some idea of the cleanliness of sand may be obtained by placing it in the palm of one hand and rubbing it with the fingers of the other. If the sand is dirty, it will badly discolor the palm of the hand. When it is found necessary to use dirty sand the strength of the concrete should be tested.

Sand containing loam or earthy material is cleansed by washing with water, either in a machine specially designed for the purpose, or by agitating the sand with water in boxes provided with holes to permit the dirty water to flow away.

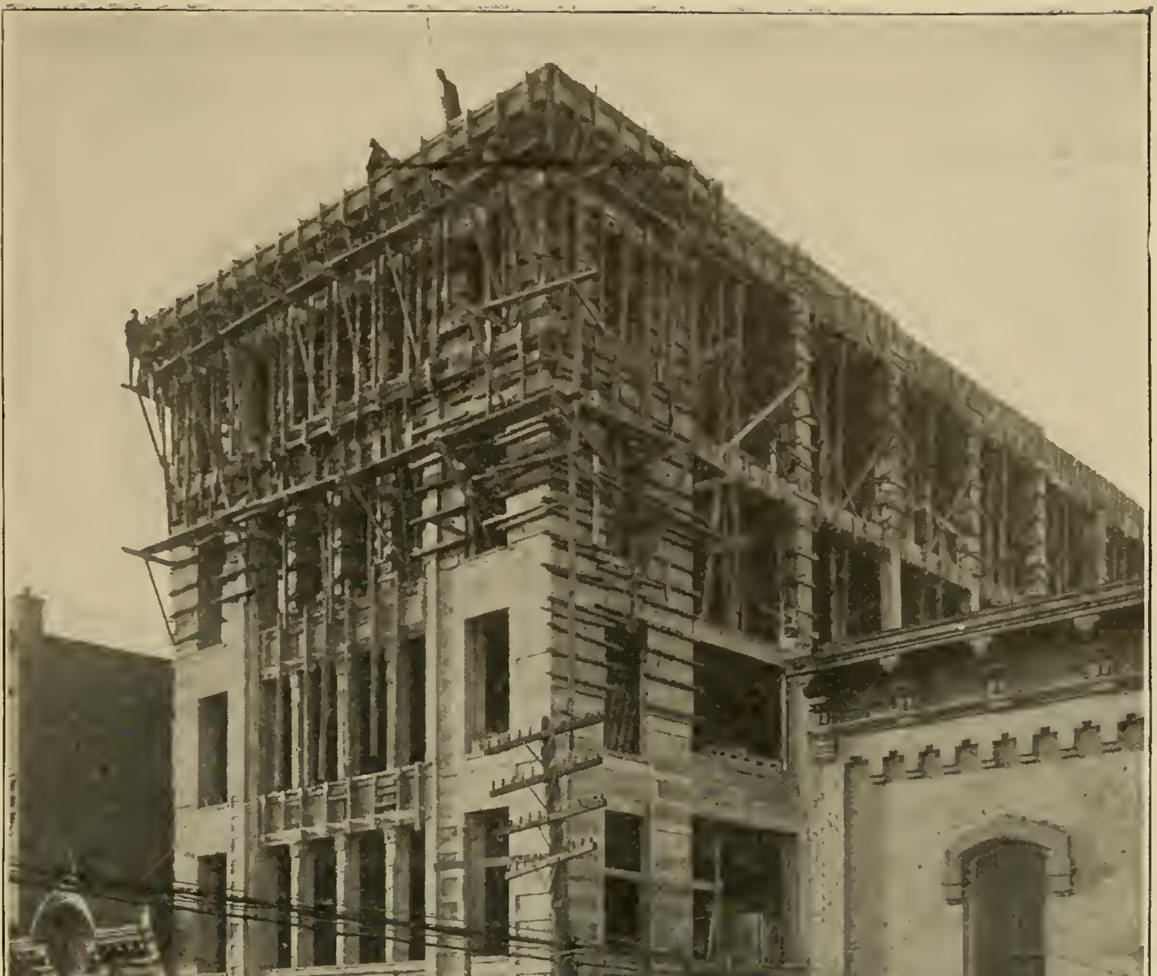
Very fine sand may be used alone, but it makes a weaker concrete than either coarse sand or coarse and fine sand mixed. A mortar consisting of very fine sand and cement will not be so dense as one of coarse sand and the same cement, although when measured or weighed dry, each contain the same proportion of voids and solid matter. In a unit measure of fine sand there are more grains than in a unit measure of coarse sand, and therefore more points of contact. More water is required in gauging a mixture of fine sand and cement than in a mixture of coarse sand and the same cement. The water forms a film and separates the grains, thus producing a larger volume having less density.

The screenings of broken stone are sometimes used instead of sand. Tests frequently show a stronger concrete when screenings are used than when sand is used. This is perhaps due to the variable sizes of the screenings, which would have a less percentage of voids.

Stone. The stone used in concrete should be hard and durable, such as trap, granite, lime stone, sand stone or a conglomerate. Lime stone should not be used as a fireproofing material as heat will calcinate it. Trap rock and gravel are perhaps the best stone for fireproof purposes. Crushed stone should have all the dust removed by a ¼-inch screen, although it may be replaced again as a part of the sand. If the product from the crusher is shown by frequent sampling to be uniform, the dust may be retained in place of a corresponding amount of sand.

The maximum size of stone usually permitted in plain concrete is 2½ inches, and in reinforced concrete ¾ inch, although in some reinforced concrete structures 1 inch stone is permitted. Sometimes specifications state that the stone to be used shall be screened to a practically uniform size, while other specifications state that the stone shall be of graduated sizes so that the smaller shall fit into the voids between the larger so that less mortar is required. A single size of broken stone has a greater tendency to form arches while being rammed into place, than stone of graded sizes. The graded stone makes a denser, stronger, and more economical concrete. Usually in graded stone for reinforced concrete the stones vary in size from ¼ inch to ¾ or 1 inch and in plain concrete from ¼ inch to 2½ inches.

Gravel. When gravel is used instead of stone, or is mixed with



VANDEVENTER BUILDING, KNOXVILLE, TENN.

Leon Beaver, Architect. Reinforcing bars furnished by Expanded Metal and Corrugated Bar Co.

stone, it should be composed of clean pebbles free from clay or other materials. A film of dirt on the gravel lessens the strength of the concrete. Graded round gravel contains a smaller percentage of voids than angular stones and makes a dense concrete which compares very well with stone concrete. The greater density of the gravel concrete tends to overcome the slight difference in strength due to the varying character of the surfaces of the particles of the gravel and the broken stone. Sometimes it is economical to mix a small percentage of gravel with broken stone.

Cinders. Cinders for concrete should be free from coal or soot. Usually a better mixture can be obtained by screening the fine stuff from the cinders and then mixing in a larger proportion of sand, than by using unscreened material, although if the fine stuff is uniformly distributed through the mass, it may be used without screening and a less proportion of sand used.

As shown later the strength of cinder concrete is far less than that of stone concrete and on this account it cannot be used where high compressive values are necessary. But on account of its very low cost compared with broken stone, especially under some conditions, it is used quite commonly for roofs, etc., on which the loads are comparatively small.

One possible objection to the use of cinders lies in the fact that they frequently contain sulphur and other chemicals which may produce corrosion of the reinforcing steel. In any structure where the strength of the concrete is a matter of importance, cinders should not be used without a thorough inspection and even then the unit compressive values allowed should be at a very low figure.

Proportions of Concrete. When large and important structures are to be built, or when the concrete is to be water tight, it pays from an economical standpoint to make a thorough study of the material of the aggregates and their relative proportions. The proportions below will serve as a guide for various classes of work.

A rich mixture, proportions 1:2:4, that is 1 barrel (4 bags) packed Portland cement (as it comes from the manufacturer), 2 barrels (7.6 cubic feet) loose sand, and 4 barrels (15.2 cubic feet) loose stone, is used in arches, reinforced concrete floors, beams and columns for heavy loads, engine and machine foundations subject to vibrations, tanks, and for water-tight work.

A medium mixture, proportions 1 : 2½ : 5, that is, 1 barrel (4 bags) packed Portland cement, 2½ barrels (9.5 cubic feet) loose sand, and 5 barrels (19 cubic feet) loose gravel or stone, may be used in arches, thin walls, floors, beams, sewers, sidewalks, foundations, and machine foundations.

An ordinary mixture, proportions 1 : 3 : 6, that is, 1 barrel (4 bags) packed Portland cement, 3 barrels (11.4 cubic feet) loose sand, and 6 barrels (22.8 cubic feet) loose gravel or broken stone, may be used for retaining walls, abutments, piers, floor slabs, and beams.

A lean mixture, proportions 1 : 4 : 8, that is, 1 barrel (4 bags) packed Portland cement, 4 barrels (15.2 cubic feet) loose sand, and 8 barrels (30.4 cubic feet) loose gravel or broken stone, may be used in large foundations supporting stationary loads, backing for stone masonry, or where it is subject to a plain compressive load.

These proportions must not be taken as always being the most economical to use, but they represent average practice. Cement is the most expensive ingredient; therefore a reduction of the quantity of cement, by adjusting the proportions of the aggregate so as to produce a concrete with the same density, strength, and impermeability, is of great importance. By careful proportioning and workmanship water-tight concrete has been made of a 1 : 3 : 6 mixture. In floor construction where the span is very short and it is specified that the slab must be at least 4 inches thick, while with a high grade concrete a 3-inch slab would carry the load, it is certainly more economical to use a leaner concrete.

The method often used in determining the voids in stone and in sand, by finding the quantity of water that can be poured into the voids of a unit measure of stone or sand and then taking that amount of sand or cement as the amount required to fill the voids in the stone or sand, is not satisfactory. The greatest inaccuracy of this method is due to the difference in compactness of the materials under varied methods of handling, and to the fact that the actual volume of voids in a coarse material may not correspond to the quantity of sand required to fill the voids. The grains of sand separate the stone and with most aggregates a portion of the sand is too coarse to get in the voids of the coarser material. That is, in a mass of crusher-run broken stone many of the individual voids are so small that the larger grain of natural bank sand will not fit into them, but will get between the stones and increase the bulk of the mass. This increase in bulk means that more sand is required than the actual volume of voids in the coarse material.

An accurate and simple method to determine the proportions of concrete is by trial batches. The apparatus consists of a scale and a cylinder which may be a piece of wrought iron pipe 10 inches to 12 inches in diameter capped at one end. Measure and weigh the cement, sand, stone, and water and mix on a piece of sheet steel, the mixture having a consistency the same as to be used in the work. The mixture is placed in the cylinder, carefully tamped, and the height to which the pipe is filled is noted. The pipe should be weighed before and after being filled so as to check the weight of the material. The cylinder is then emptied and cleaned. Mix up another batch using the same amount of cement and water, slightly varying the ratio of the sand and stone but having the same total weight as before. Note the height in the cylinder, which will be a guide to other batches to be tried. Several trials are made until a mixture is found that gives the least height in the cylinder, and at the same time works well while mixing, all the stones being covered with mortar, and which makes a good appearance. This method gives very good results, but it does not indicate the changes in the physical sizes of the sand and stone so as to secure the most economical composition as would be shown in a thorough mechanical analysis.

There has been much concrete work done where the proportions were selected without any reference to voids, which has given much better results in practice than might be expected. The proportion of cement to the aggregate depends upon the nature of the construction and the required degree of strength, or water-tightness, as well as upon the character of the inert materials. Both strength and imperviousness increase with the proportion of cement to the aggregate. Richer mixtures are necessary for loaded columns, beams in building construction and arches, for thin walls subject to water pressure, and for foundations laid under water. The actual measurements of materials as actually mixed and used usually show leaner mixtures than the nominal proportions specified. This is largely due to the heaping of the measuring boxes.

TABLE II

Proportions of Cement, Sand, and Stone in Actual Structures

STRUCTURE	PROPORTIONS	REFERENCE
C. B. & Q. R. R.		
Reinforced Concrete Culverts	1:3:6	Engr. Cont., Oct. 3, '06
Phila. Rapid Transit Co.		
Floor Elevated Roadway....	1:3:6	" " Sept. 26, '06
Subway { Walls...........	1:2.5:5	
Subway { Floors...........	1:3:6	
C. P. R. R.		
Arch Rings..................	1:3:5	
Piers and Abutments........	1:4:7	Cement Era, Aug. '06
Hudson River Tunnel Caisson	1:2:4	Eng. Record, Sept. 29, '06
Stand Pipe at Attleboro, Mass. Height, 106 feet.	1:2:4	" " " 29, '06
C.C.& St.L.R.R., Danville Arch		
Footings....................	1:4:8 or 1:9.5	" " March 3, '06
Arch Rings..................	1:2:4	
Abutments, Piers............	1:3:6 or 1:6.5	
N. Y. C. & H. R. R. R.		
Ossining Tunnel { Footing..........	1:4:7.5	" " " 3, '06
Ossining Tunnel { Walls...........	1:3:6	
Ossining Tunnel { Coping..........	1:2:4	
American Oak Leather Co. Factory at Cincinnati, Ohio.	1:2:4	" " " 3, '03
Harvard University Stadium..	1:3:6	
New York Subway		
Roofs and Sidewalks........	1:2:4	
Tunnel Arches.............	1:2.5:5	
Wet Foundation 2′ th. or less	1:2:4	
" " exceeding 2′	1:2.5:5	
Boston Subway...............	1:2.5:4	
P. & R. R. R.		
Arches.....................	1:2:4	" " Oct. 13, '06
Piers and Abutments........	1:3:6	
Brooklyn Navy Yd. Laboratory		
Columns....................	1:2:3 Trap rock	Eng. News, March 23, '05
Beams and Slabs............	1:3:5 " "	
Roof Slab..................	1:3:5 Cinder	
Southern Railway		
Arches.....................	1:2:4	
Piers and Abutments........	1:2.5:5	

Methods of Mixing Concrete. The method of mixing concrete is immaterial, if a homogeneous mass is secured of a uniform consistency, containing the cement, sand, and stone in the correct proportions. The value of the concrete depends greatly upon the thoroughness of the mixing. The color of the mass must be uniform, every grain of sand and piece of the stone should have cement adhering to every point of its surface.

TABLE III

Barrels of Portland Cement Per Cubic Yard of Mortar

(Voids in Sand Being 35 per cent and 1 Bbl. Cement Yielding 3.65 Cubic Feet of Cement Paste.)

PROPORTION OF CEMENT TO SAND	1:1	1:1.5	1:2	1:2.5	1:3	1:4
	Bbls.	Bbls.	Bbls.	Bbls.	Bbls.	Bbls.
Bbl. specified to be 3.5 cu. ft.	4.22	3.49	2.97	2.57	2.28	1.76
" " " 3.8 "	4.09	3.33	2.81	2.45	2.16	1.62
" " " 4.0 "	4.00	3.24	2.73	2.36	2.08	1.54
" " " 4.4 "	3.81	3 07	2.57	2.27	2.00	1 40
Cu. yds. sand per cu. yd. mortar. ..	0.6	0.7	0.8	0.9	1.0	1.0

TABLE IV

Barrels of Portland Cement Per Cubic Yard of Mortar

(Voids in Sand Being 45 per cent and 1 Bbl. Cement Yielding 3.4 Cubic Feet of Cement Paste.)

PROPORTION OF CEMENT TO SAND	1:1	1:1.5	1:2	1:2.5	1:3	1:4
	Bbls.	Bbls.	Bbls.	Bbls.	Bbls.	Bbls.
Bbl. specified to be 3.5 cu. ft.	4.62	3.80	3.25	2.84	2.35	1.76
" " " 3.8 "	4.32	3.61	3.10	2.72	2.16	1.62
" " " 4 0 "	4.19	3.46	3.00	2.64	2.05	1.54
" " " 4.4 "	3.94	3.34	2.90	2.57	1.86	1.40
Cu. yds. sand per cu. yds. mortar. .	0.6	0.8	0.9	1.0	1.0	1.0

TABLE V

Ingredients in 1 Cubic Yard of Concrete

(Sand Voids, 40 per cent; Stone Voids, 45 per cent; Portland Cement Barrel Yielding 3.65 cu. ft. Paste. Barrel specified to be 3.8 cu. ft.)

PROPORTIONS BY VOLUME	1:2:4	1:2:5	1:2:6	1:2.5:5	1:2.5:6	1:3:4
Bbls. cement per. cu. yd. concrete. .	1.46	1.30	1.18	1.13	1.00	1.25
Cu. yds. sand " " ..	0.41	0.36	0.33	0.40	0.35	0.53
" stone " " ..	0.82	0.90	1.00	0.80	0.84	0.71
Proportions by volume............	1:3:5	1:3:6	1:3:7	1:4:7	1:4:8	1:4:9
Bbls. cement per cu. yd. concrete. .	1.13	1.05	0.96	0.82	0.77	0.73
Cu. yds. sand " " ..	0.48	0.44	0.40	0.46	0.43	0.41
" stone " " ..	0.80	0.88	0.93	0.80	0.86	0.92

This table is to be used when cement is measured packed in the barrel, for the ordinary barrel holds 3.8 cu. ft.

TABLE VI

Ingredients in 1 Cubic Yard of Concrete

(Sand Voids, 40 per cent; Stone Voids, 45 per cent; Portland Cement Barrel Yielding 3.65 cu. ft. of Paste. Barrel specified to be 4.4 cu. ft.)

Proportions by Volume	1:2:4	1:2:5	1:2:6	1:2.5:5	1:2.5:6	1:3:4
Bbls. cement per cu. yd. concrete...	1.30	1.16	1.00	1.07	0.96	1.08
Cu. yds. sand " " ...	0.42	0.38	0.33	0.44	0.40	0.53
" stone " " ...	0.84	0.95	1.00	0.88	0.95	0.71
Proportions by volume............	1:3:5	1:3:6	1:3:7	1:4:7	1:4:8	1:4:9
Bbls. cement per cu. yd. concrete...	0.96	0.90	0.82	0.75	0.68	0.64
Cu. yds. sand " " ...	0.47	0.44	0.40	0.49	0.44	0.42
" stone " " ...	0.78	0.88	0.93	0.86	0.88	0.95

This table is to be used when the cement is measured loose, after dumping it into a box, for under such conditions a barrel of cement yields 4.4 cu. ft. of loose cement.

[Tables II to VI have been taken from Gillette's Handbook of Cost Data.]

The two methods used in mixing concrete are by hand and by machinery. Good concrete may be made by either method. Concrete mixed by either method should be carefully watched by a good foreman. If a large quantity of concrete is required it is cheaper to mix it by machinery. On small jobs where the cost of erecting the plant and the interest and depreciation, divided by the number of cubic yards to be made, is a large item, or if frequent moving is required, it is very often cheaper to mix the concrete by hand. The relative cost of the two methods usually depends upon circumstances, and must be worked out in each individual case.

Hand Mixing. The placing and handling of materials and arranging the plant is varied by different engineers and contractors. In general the mixing of concrete is a simple operation but should be carefully watched by an inspector. He should see:

(1) That the exact amount of stone and sand are measured out.
(2) That the cement and sand are thoroughly mixed.
(3) That the mass is thoroughly mixed.
(4) That the proper amount of water is used.
(5) That care is taken in dumping the concrete in place.
(6) That it is thoroughly rammed.

The mixing platform, which is usually 10 to 20 feet square, is made of 1-inch or 2-inch plank planed on one side and well nailed to stringers, and should be placed as near the work as possible, but so situated that the stone can be dumped on one side of it and the sand on the opposite side. A very convenient way to measure the stone and sand is by the means of bottomless boxes. These boxes are of such a size that they hold the proper proportions of stone or sand to mix a batch of a certain amount. Cement is usually measured by the package, that is by the barrel or bag, as they contain a definite amount of cement.

The method used for mixing the concrete has little effect upon the strength of the concrete, if the mass has been turned a sufficient number of times to thoroughly mix them. One of the following methods is generally used. (Taylor and Thompson's *Concrete.*)

(a) Cement and sand mixed dry and shoveled on the stone or gravel, leveled off, and wet as the mass is turned.

(b) Cement and sand mixed dry, the stone measured and dumped on top of it, leveled off, and wet, as turned with shovels.

(c) Cement and sand mixed into a mortar, the stone placed on top of it and the mass turned.

(d) Cement and sand mixed with water into a mortar which is shoveled on the gravel or stone and the mass turned with shovels.

(e) Stone or gravel, sand, and cement spread in successive layers, mixed slightly and shoveled into a mound, water poured into the center, and the mass turned with shovels.

The quantity of water is regulated by the appearance of the concrete. The best method of wetting the concrete is by measuring the water in pails. This insures a more uniform mixture than by spraying the mass with a hose.

Mixing by Machinery. On large contracts the concrete is generally mixed by machinery. The economy is not only in the mixing itself but in the appliances introduced in handling the raw materials and the mixed concrete. If all materials are delivered to the mixer in wheel-barrows, and if the concrete is conveyed away in wheel-barrows, the cost of making concrete is high, even if machine mixers are used. If the materials are fed from bins by gravity into the mixer, and if the concrete is dumped from the mixer into cars and hauled away, the cost of making the concrete should be very low. On small jobs the cost of maintaining and operating the mixer will usually exceed the saving in hand labor and will render the expense with the machine greater than without it.

The design of a plant for handling the material and concrete, and the selection of a mixer, depend upon local conditions, the amount of concrete to be mixed per day, and the total amount required on the contract. It is very evident that on large jobs it pays to invest a large sum in machinery to reduce the number of men and horses, but if not over 50 cubic yards are to be deposited per day the cost of the machinery is a big item and hand labor is generally cheaper. The interest on the plant must be charged against the number of cubic yards of concrete; that is, the interest on the plant for a year must be charged to the number of cubic yards of concrete laid in a year. The depreciation of the plant is found by taking the cost of the entire plant when new, and then appraising it after the contract is finished, and dividing the difference by the total cubic yards of concrete laid. This will give the depreciation per cubic yard of concrete manufactured.

Concrete Mixers. The best concrete mixer is the one that turns out the maximum of thoroughly mixed concrete at the minimum of cost for power, interest, and maintenance. The type of mixer with a complicated motion gives better and quicker results than one with a simpler motion. There are two general classes of concrete mixers; *continuous* mixers and *batch* mixers. A *continuous* mixer is one into which the materials are fed constantly and from which the concrete is discharged constantly. *Batch* mixers are constructed to receive the cement with its proportionate amount of sand and stone all at one charge, and when mixed it is discharged in a mass. A very distinct line cannot be drawn between these two classes, for many of these mixers are adapted to either continuous or batch mixing. Generally batch mixers are preferred, as it is a very difficult matter to feed the mixers uniformly unless the materials are mechanically measured.

Continuous mixers usually consist of a long screw or pug mill, that pushes the materials along a drum until they are discharged in a continuous stream of concrete. Where the mixers are fed with automatic measuring devices the concrete is not regular as there is no reciprocating motion of the materials. In a paper recently read before the Association of American Portland Cement Manufacturers by S. B. Newberry, he states: "For the preparation of concrete for blocks in which thorough mixing and use of an exact and uniform proportion of water are necessary, continuous mixing machines are unsuitable, and batch mixers, in which a measured batch of the material is mixed the required time, and then discharged, are the only type which will be found effective."

There are three general types of concrete mixers: *gravity* mixers, *rotary* mixers, and *paddle* mixers.

Gravity mixers are the oldest type of concrete mixers. They require no power, the materials being mixed by striking obstructions which throw them together in their descent through the machine. Their construction is very simple. Fig. 7 illustrates a portable gravity mixer. This mixer, as will be seen by the figure, is a steel trough or shoot in which are contained mixing members consisting of pins or blades. The mixer is portable and requires no skilled labor to operate it. There is nothing to get out of order or cause delays. It is adapted for both large and small jobs. In the former case, it is usually fed by measure and by this method will produce concrete as fast as the materials can be fed to their respective bins and the mixed concrete can be taken from the discharge end of the mixer. On very small jobs, the best way to operate is to measure the batch in layers of stone, sand, and cement respectively and feed to the mixer by men with shovels.

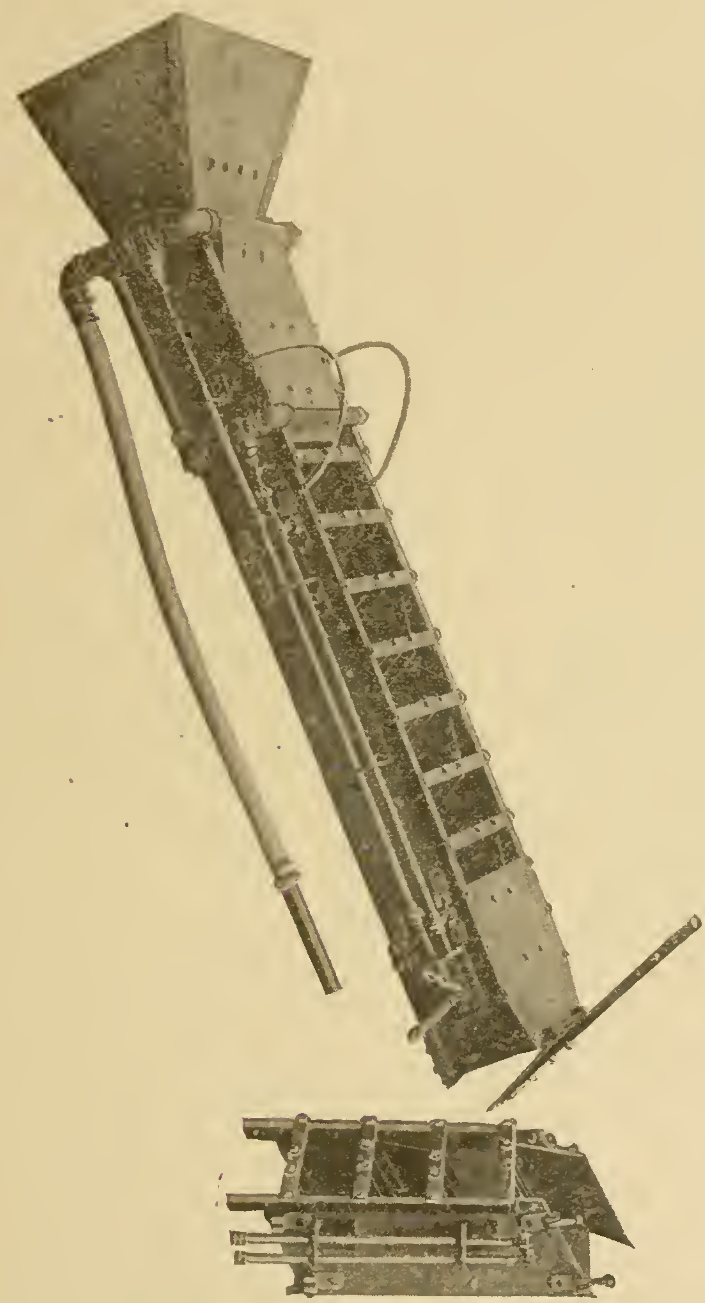


Fig. 7. Portable Gravity Mixer.

There are two spray pipes placed on the mixer: for feeding by hand one spray only would be used; the other spray is only intended for use when operating with the measure and feeder, and a large amount of water is required. These sprays are operated by handles which control two gate valves and regulate the quantity of water which flows from the spray pipes.

These mixers are made in two styles, sectional and non-sectional. The sectional can be made either 4, 6, or 8 feet long. The non-sectional are in one length of 6, 8, or 10 feet. Both are constructed of $\frac{1}{8}$-inch steel. To operate this mixer, the materials must be raised to a platform, as shown in Fig. 8.

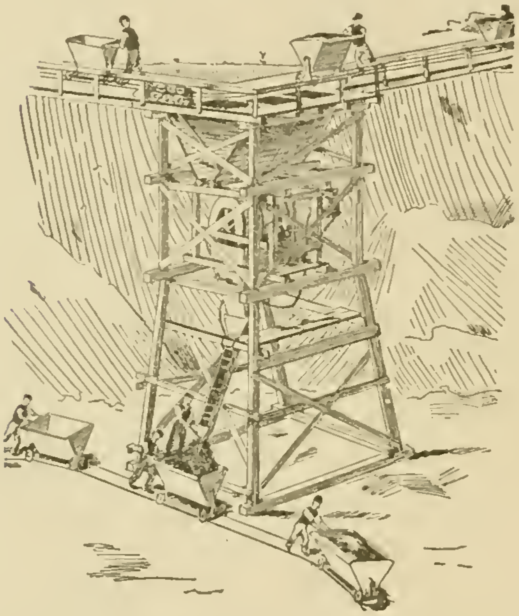


Fig. 8. Operation of Portable Gravity Mixer.

Rotary mixers, Fig. 9, generally consist of a cubical box made of steel and mounted on a wooden frame. This steel box is supported by a hollow shaft through two diagonally opposite corners and the water is supplied through openings in the hollow shaft. Materials are dropped in at the side of the mixer through a hinged door. The machine is then revolved several times, usually about 15 times, the door is opened, and the concrete is dumped out into carts or cars. There are no paddles or blades of any kind inside the box to assist in the mixing. This mixer is not expensive itself, but the erection of the frame and the hoisting of the stone and sand often render it less economical than some of the more expensive devices.

Rotating mixers which contain reflectors or blades, Fig. 10, are usually mounted on a suitable frame by the manufacturers. The rotating of the drum tumbles the material and it is thrown against the mixing blades which cut it and throw it from side to side. Many of these machines can be filled and dumped while running, either by tilting or by their shutes. Fig. 10 illustrates the Smith mixer and Fig. 11 gives a sectional view of the drum and shows the arrangement of the blades. This mixer is furnished on skids with driving pulley. The concrete is discharged by tilting the drum, which is done by power.

Fig. 12 represents a Ransome mixer which is a batch mixer. The concrete is discharged after it is mixed, without tilting the body of the mixer. It revolves continuously even while the concrete is being discharged. Riveted to the inside of the drum is a number of steel scoops or blades. "These scoops pick up the material in the bottom of the mixer, and, as the mixer revolves, carry the material upward until it slides out of the scoops" and therefore assists in mixing the materials.

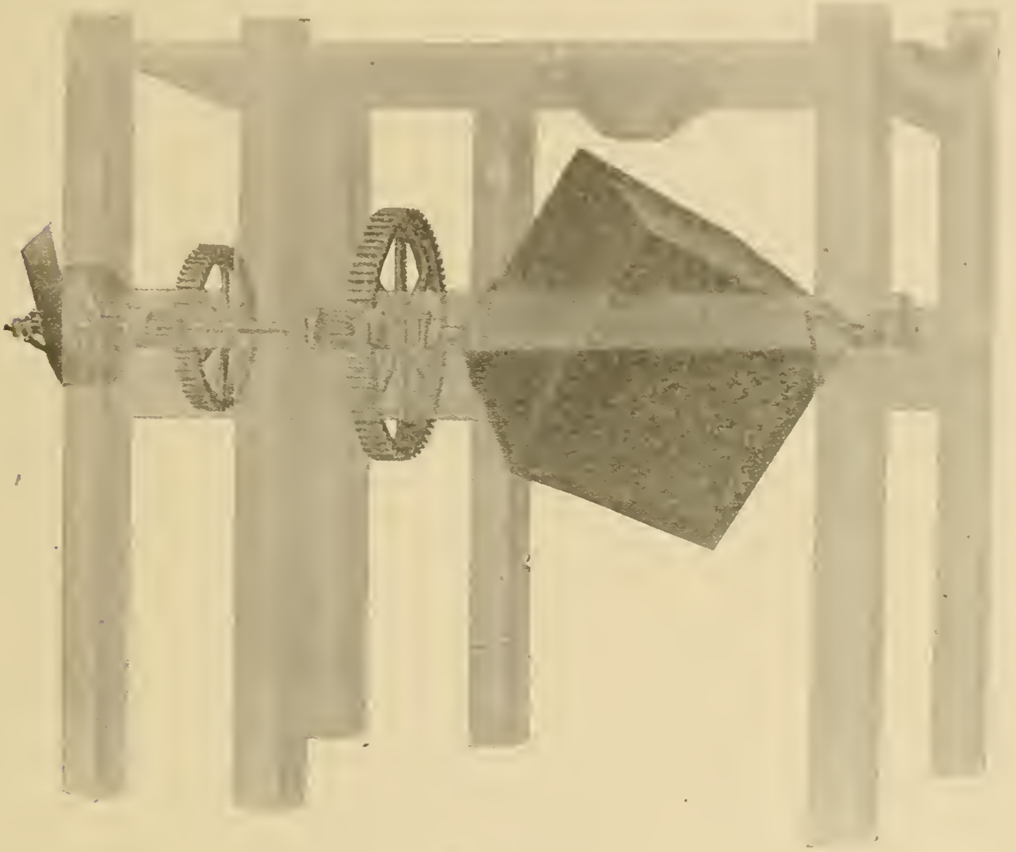


Fig. 9. Rotary Mixer with Cubical Box.

Fig. 13 represents a McKelvey batch mixer. In this mixer, the lever on the drum operates the discharge. The drum is fed and discharged while in motion and does not change its direction or its position in either feeding or discharging. The inside of the drum is provided with blades to assist in the mixing of the concrete.

Paddle mixers may be either continuous or of the batch type. Mixing paddles, on two shafts, revolve in opposite directions and the

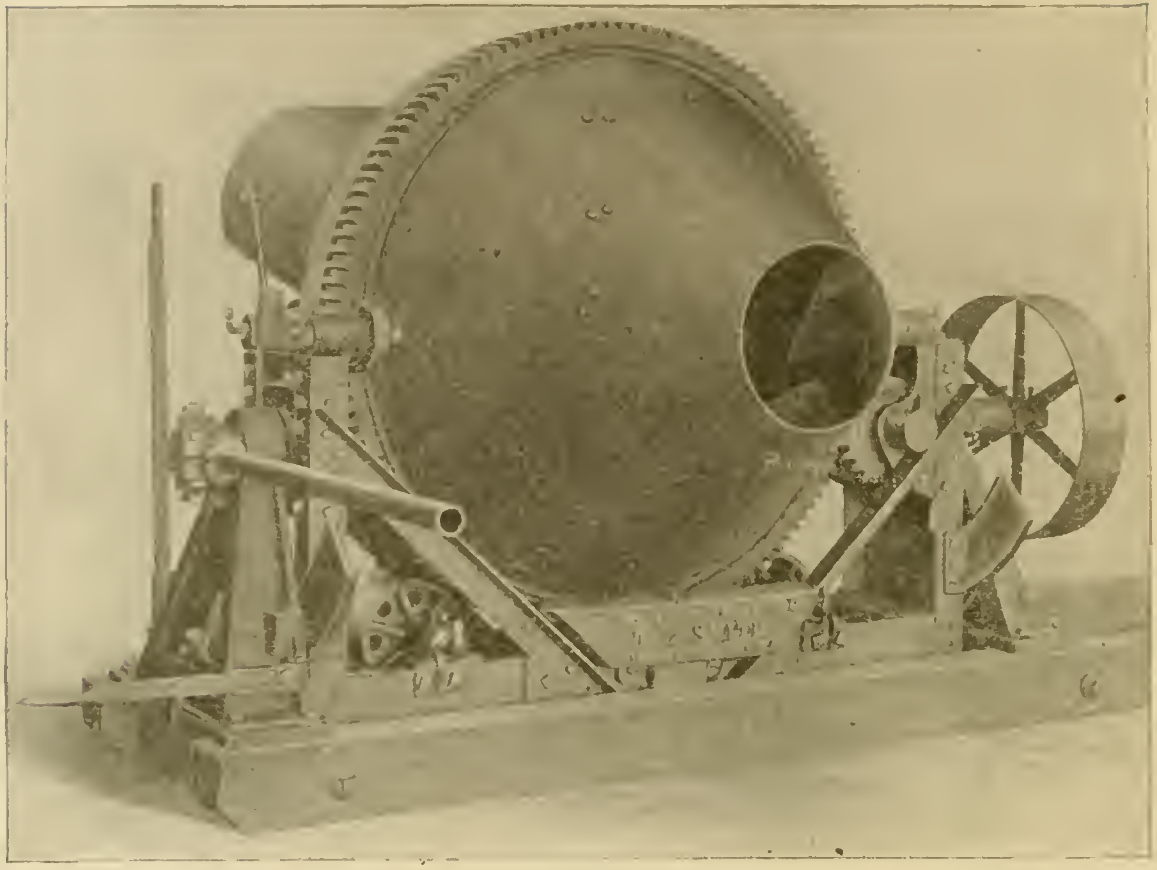


Fig. 10. Rotary Mixer Mounted on Frame.

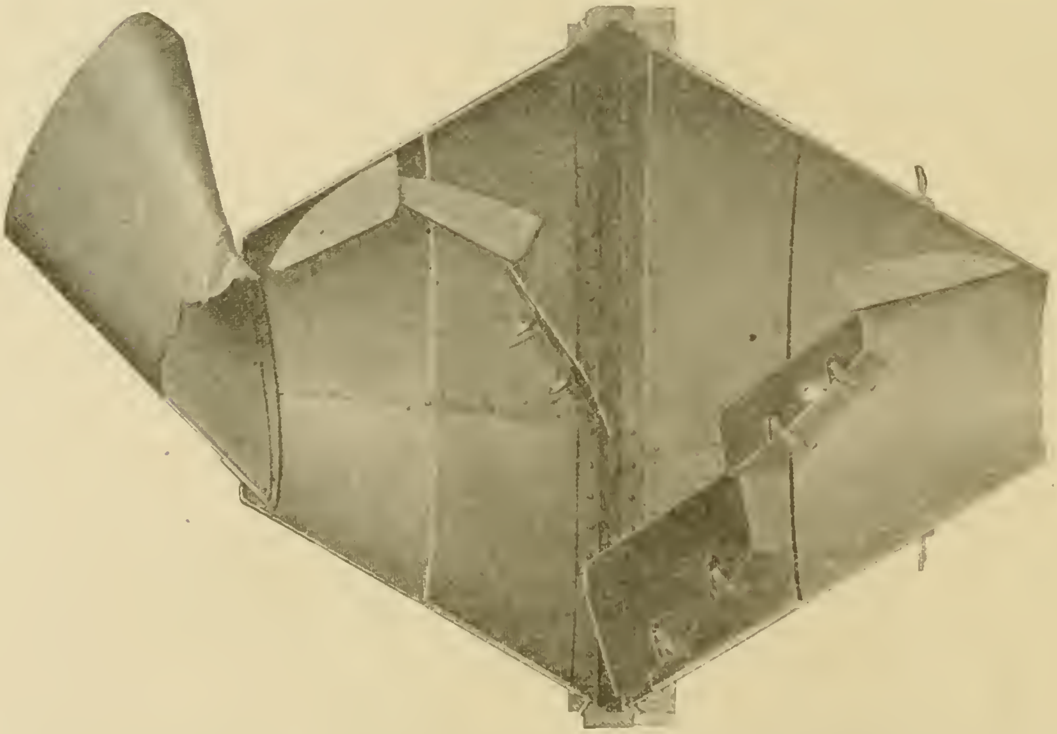


Fig 11. Cross Section of Drum (front half cut away). Showing Blades and Lining

concrete falls through a trap door in the bottom of the machine. In the continuous type the materials should be put in at the upper end so as to be partially mixed dry. The water is supplied near the middle of the mixer. Fig. 14 represents a type of the paddle mixer.

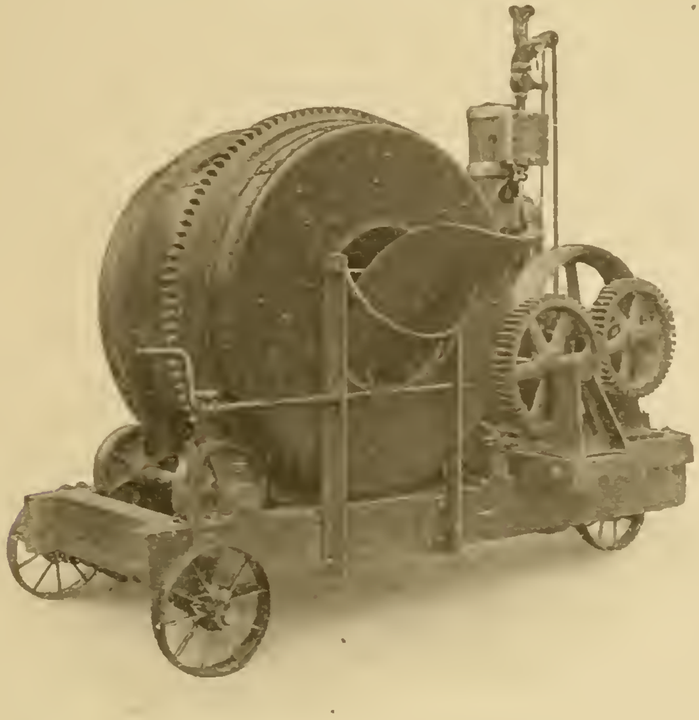


Fig. 12. Ransome Batch Mixer.

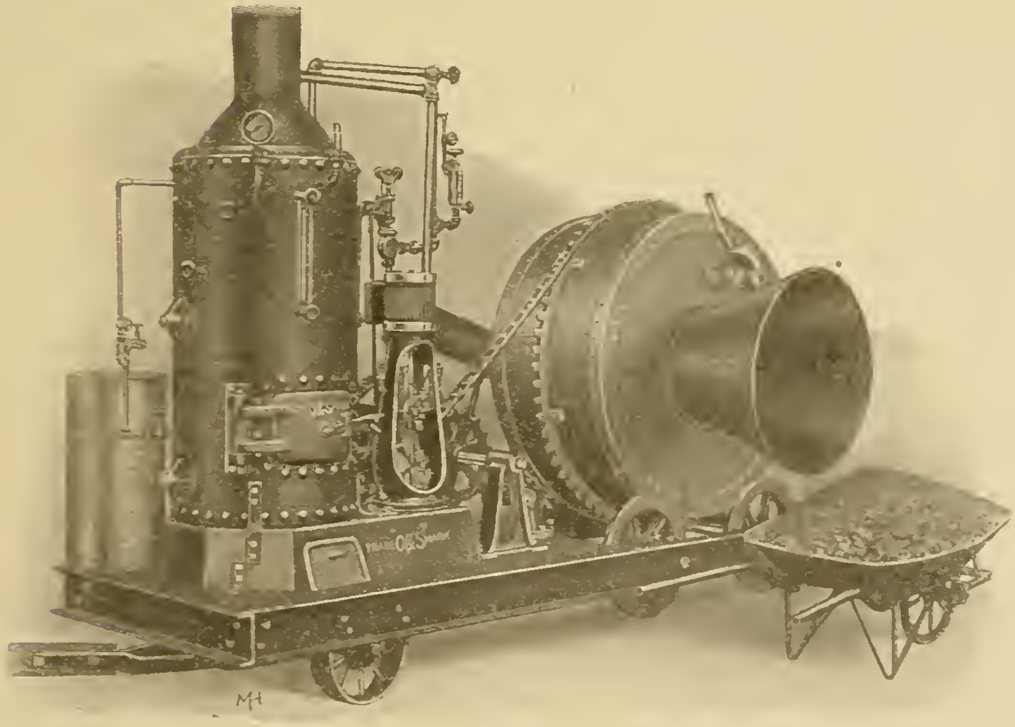


Fig. 13. McKelvey Batch Mixer.

Automatic Measures for Concrete Materials. Mechanical measuring machinery for concrete materials have not been very extensively developed. One difficulty is that they require the constant attention of an attendant unless the materials are perfectly uniform. If the machine is adjusted for sand with a certain percentage of moisture and then is suddenly supplied with sand having greater or less moisture, the adjustment must be changed or the mixture will not be uniform. If the attendant does not watch the condition of the materials very closely, the proportions of the ingredients will vary greatly from what they should.

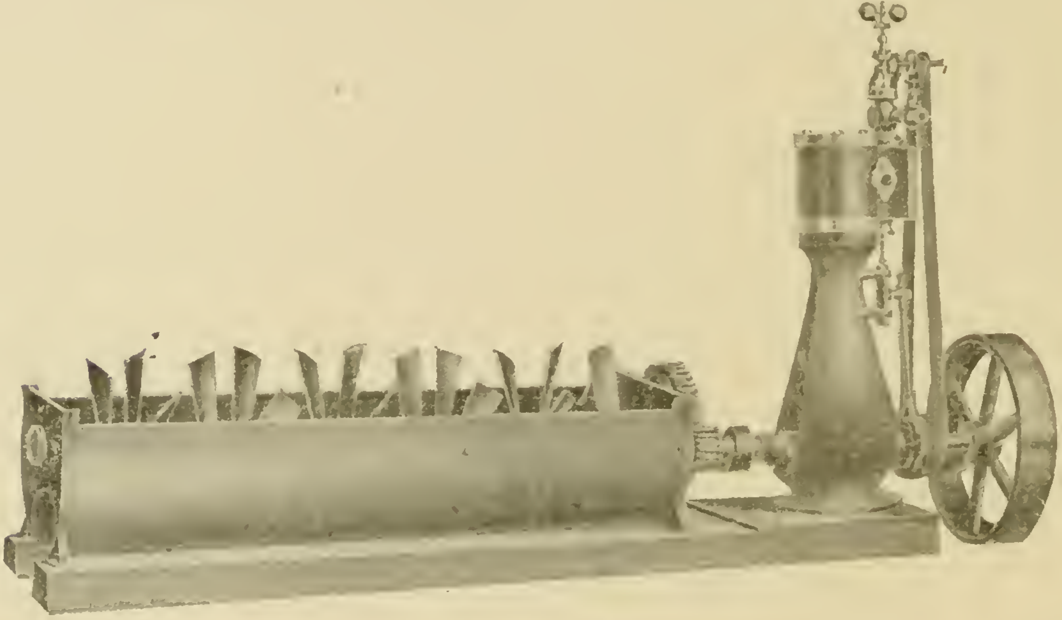


Fig. 14. Paddle Mixer.

"The *Trump* measuring device, shown in Fig. 15, consists of a horizontal revolving table on which rests the material to be measured and a stationary knife set above the table and pivoted on a vertical shaft outside the circumference. The knife can be adjusted to extend a proper distance into the material and peel off, at each revolution of the table, a certain amount which falls into the shoot. The material peeled off is replaced from the supply contained in a bottomless storage cylinder somewhat smaller in diameter than the table and revolving with it. The depth of the cut of the knife is adjusted by swinging the knife around on its pivot, so that it extends a greater or less distance into the material. The swing is controlled by a screw attached to an arm cast as part of the knife. A micrometer scale with pointer indicates the position of the knife. When it is desired to measure off and mix three materials, the machines are made with three tables set one above the other and mounted on the same spindle so that they revolve together. Each table has its own storage cylinder above it, the cylinders being placed one within the other as shown by Fig. 16."

Wetness of Concrete. The plasticity of concrete may be divided into three classes: *dry*, *medium*, and *very wet*.

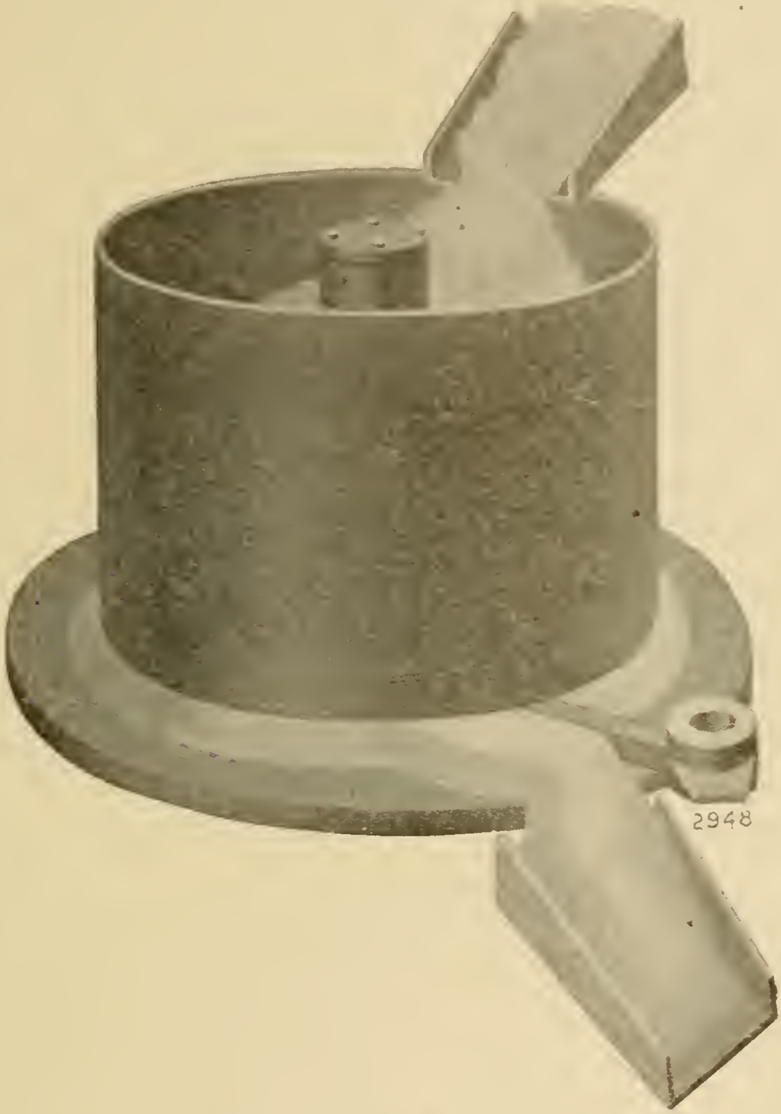


Fig. 15. Trump Measuring Device.

Dry concrete is used in foundations which may be subjected to severe compression a few weeks after being placed. It should not be placed in layers of more than 8 inches and should be thoroughly rammed. In a dry mixture the water will just flush to the surface only when it is thoroughly tamped. A dry mixture sets and will support a load much sooner than if a wetter mixture is used, and generally is only used where the load is to be applied soon after the concrete is placed. This mixture requires more than ordinary care in ramming as pockets are apt to be formed, and one argument against it is the difficulty of getting a uniform product.

Medium concrete will quake when rammed and has a consistency of liver or jelly. It is adapted for mass concrete, such as retaining walls, piers, foundations, arches, abutments, and sometimes for reinforced concrete.

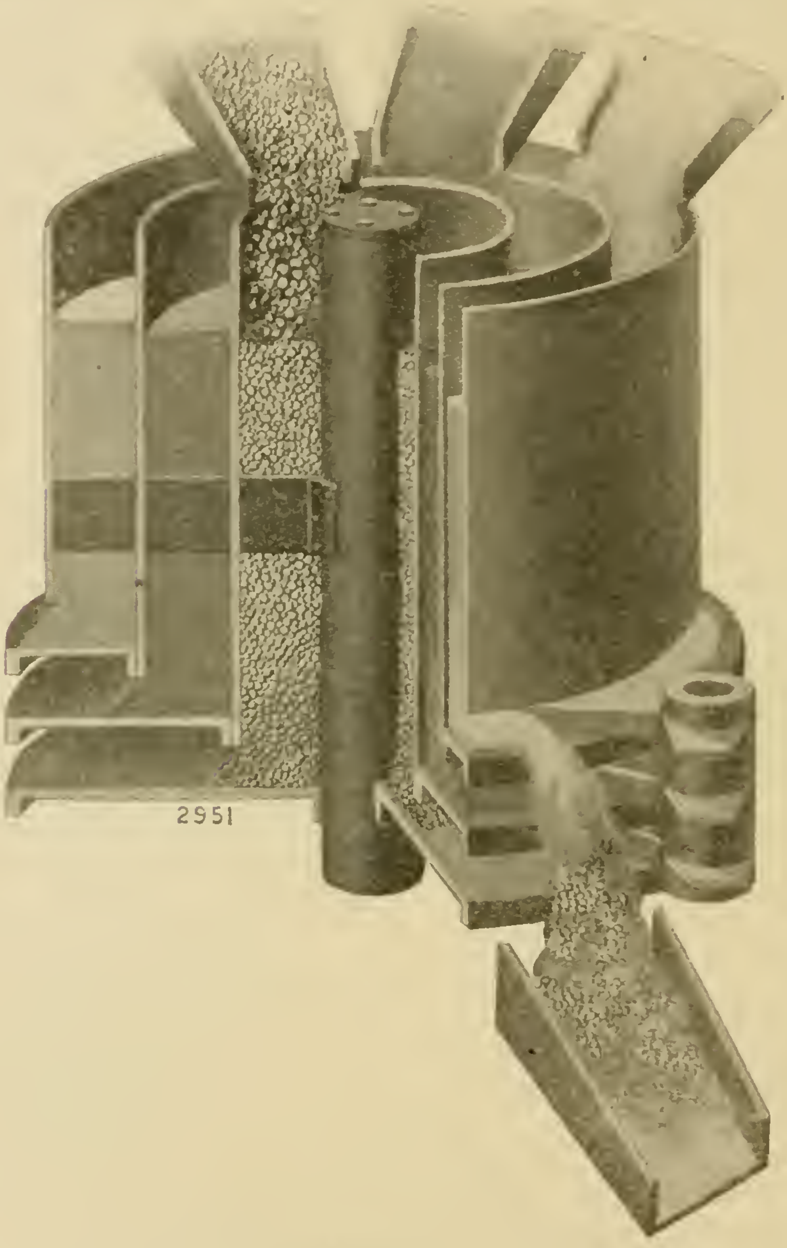
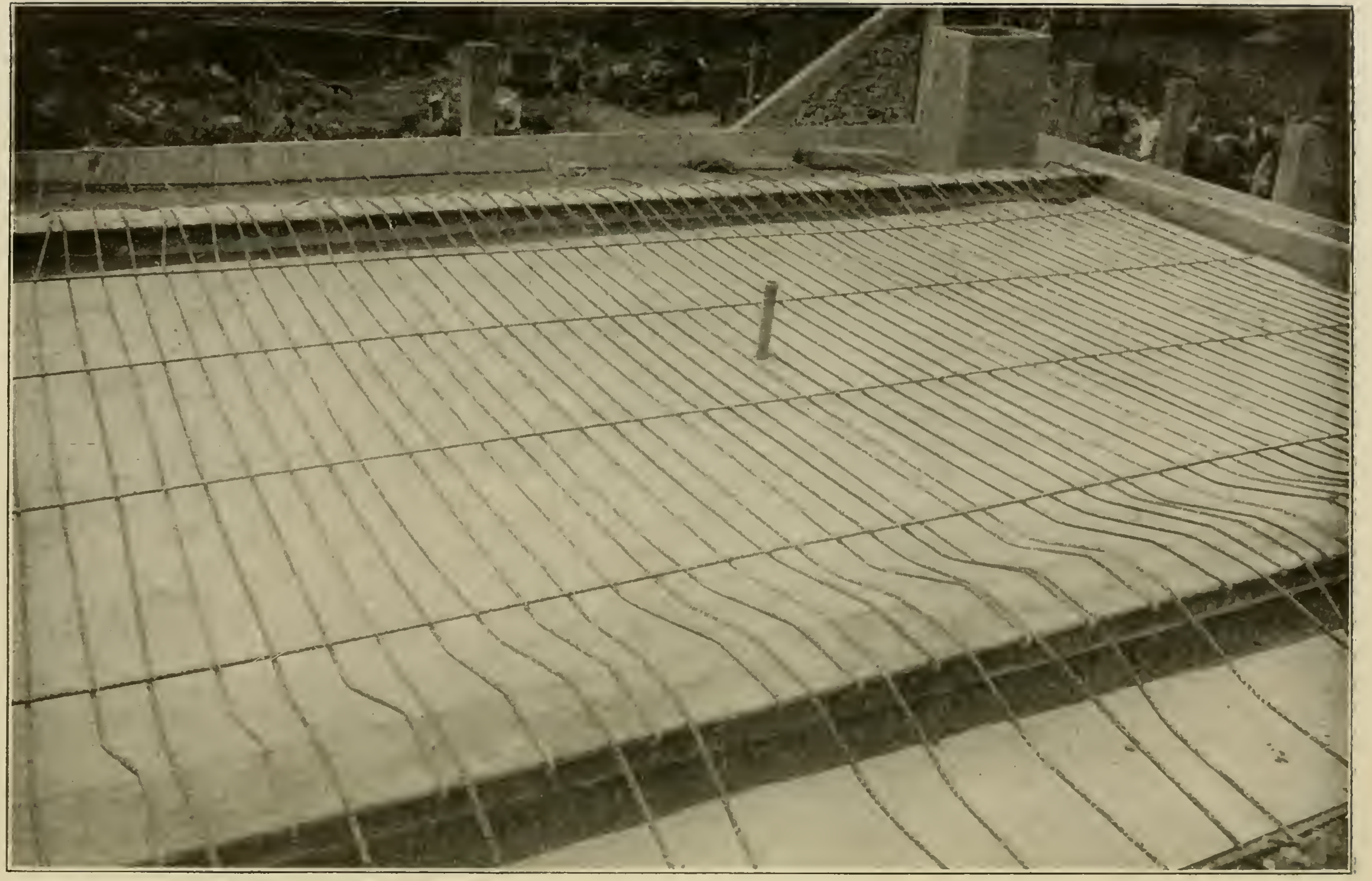


Fig. 16. Interior View of Trump Concrete Mixer.

A *Very Wet* mixture of concrete will run off a shovel unless it is handled very quickly. An ordinary rammer will sink into it of



TYPICAL FLOOR-SLAB CONSTRUCTION ON STEEL FRAME FOR A REINFORCED CONCRETE FLOOR.

Reproduced by Courtesy of Expanded Metal & Corrugated Bar Company.

its own weight. It is suitable for reinforced concrete, such as thin walls, floors, columns, tanks, and conduits.

Within the last few years there has been a marked change in the amount of water used in mixing concrete. The dry mixture has been superseded by a medium or very wet mixture, often so wet as to require no ramming whatever. Experiments have shown that *dry mixtures* give better results in *short time tests* and *wet mixtures* in *long time tests*. In some experiments made on dry, medium, and wet mixtures it was found that the medium mixture was the most dense, wet next, and dry least. This experimenter concluded that the medium mixture is the most desirable, since it will not quake in handling, but will quake under heavy ramming. He found medium 1 per cent denser than wet and 9 per cent denser than dry concrete; he considers thorough ramming important.

Concrete is often used so wet that it will not only quake but flow freely, and after setting it appears to be very dense and hard, but some engineers think that the tendency is to use far too much rather than too little water, but that thorough ramming is desirable. In thin walls very wet concrete can be more easily pushed from the surface so that the mortar can get against the forms and give a smooth surface. It has also been found essential that the concrete should be wet enough so as to flow under and around the steel reinforcement so as to secure a good bond between the steel and concrete.

Following are the specifications (1903) of the American Railway Engineering and Maintenance of Way Association:

"The concrete shall be of such consistency that when dumped in place it will not require tamping; it shall be spaded down and tamped sufficiently to level off and will then quake freely like jelly, and be wet enough on top to require the use of rubber boots by workman."

Transporting and Depositing Concrete. Concrete is usually deposited in layers of 6 inches to 12 inches in thickness. In handling and transporting concrete care must be taken to prevent the separation of the stone from the mortar. The usual method of transporting concrete is by wheel-barrows, although it is often handled by cars and carts, and on small jobs it is sometimes carried in buckets. A very common practice is to dump it from a height of several feet into a trench. Many engineers object to this process as they claim that the heavy and light portions separate while falling and the concrete is therefore not uniform through its mass, and they insist that it must be gently slid into place. A wet mixture is much easier to handle than a dry mixture, as the stone will not so readily separate from the mass. A very wet mixture has been deposited from the top of forms 43 feet high and the structure was found to be waterproof. On the other hand, the stones in a dry mixture will separate from the mortar on the slightest provocation. Where it is necessary to drop a dry mixture several feet, it should be done by means of a chute or pipe.

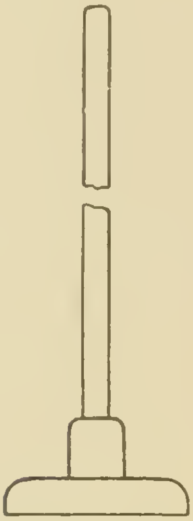


Fig. 17 Rammer for Dry Concrete. (Shoe 6 inches square.)

Ramming Concrete. Immediately after concrete is placed, it should be rammed or puddled, care being taken to force out the air-bubbles. The amount of ramming necessary depends upon how much water is used in mixing the concrete. If a very wet mixture is used, there is danger of too much ramming, which results in wedging the stones together and forcing the cement and sand to the surface. The chief object in ramming a very wet mixture is simply to expel the bubbles of air.

The style of rammer ordinarily used depends on whether a dry, medium, or very wet mixture is used. A rammer for dry concrete is shown in Fig. 17; and one for wet concrete, in Fig. 18. In very thin walls, where a wet mixture is used, often the tamping or puddling is done with a part of a reinforcing bar. A common spade is often employed for the face of work, being used to push back stones that may have separated from the mass, and also to work the finer portions of the mass to the face, the method being to work the spade up and down the face until it is thoroughly filled. Care must be taken not to pry with the spade, as this will spring the forms unless they are very strong.

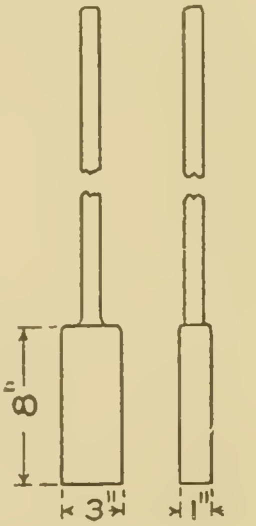


Fig. 18. Rammer for Wet Concrete.

Bonding Old and New Concrete. To secure a water-tight joint between old and new concrete, requires a great deal of care. Where the strain is chiefly compressive, as in foundations, the surface of the concrete laid on the previous day should be washed with clean water, no other precautions being necessary. In walls and floors, or where a tensile stress is apt to be applied, the joint should be thoroughly washed and soaked, and then painted with neat cement or a mixture of one part cement and one part sand, made into a very thin mortar.

In the construction of tanks or any other work that is to be water-tight, in which the concrete is not placed in one continuous operation, one or more square or V-shaped joints are necessary. These joints are formed by a piece of timber, say 4 inches by 6 inches, being imbedded in the surface of the last concrete laid each day. On the following morning, when the timber is removed, the joint is washed and coated with neat cement or 1:1 mortar. The joints may be either horizontal or vertical. The bond between old and new concrete may be aided by roughening the surface after ramming or before placing the new concrete.

Effects of Freezing of Concrete. Many experiments have been made to determine the effect of freezing of concrete before it has a chance to set. From these and from practical experience, it is now generally accepted that the ultimate effect of freezing of Portland cement concrete is to produce only a surface injury. The setting and hardening of Portland cement concrete is retarded, and the strength at short periods is lowered, by freezing; but the ultimate strength appears to be only slightly, if at all, affected. A thin scale about $\frac{1}{16}$ inch in depth is apt to scale off from granolithic or concrete pavements which have been frozen, leaving a rough instead of a troweled wearing surface; and the effect upon concrete walls is often similar; but there appears to be no other injury. Concrete should not be laid in freezing weather, if it can be avoided, as this involves additional expense and requires greater precautions to be taken; but with proper care, Portland cement concrete can be laid at almost any temperature.

The heating of the material hastens the setting of the cement, and also keeps it above the freezing point for a longer period. Salt lowers the freezing point of water, and when used in moderate quantities does not appear to affect the ultimate strength of the concrete. Authorities differ on the amount of salt that may be used;

but from four to ten pounds to each barrel of cement will not decrease the strength of the concrete.

Finish. To give a satisfactory finish to exposed surfaces of concrete is rather a difficult problem. Usually, when the forms are taken down, the surface of the concrete shows the joints, knots, and grain of the wood. It has more the appearance of a piece of rough carpentry work than of finished masonry. Some special treatment is therefore necessary. Plastering is not usually successful, although there are cases where a mixture of equal parts of cement and sand have apparently been successful. Where finished rough, it did not show hair-cracks; but when finished smooth, it did show them. In constructing the Harvard University Stadium, care was taken, after the concrete was placed in the forms, to force the stones back from the face and permit the mortar to cover every stone. When the forms were removed, the surface was picked with a tool as shown in Fig. 19. A pneumatic tool has also been adopted for this purpose.

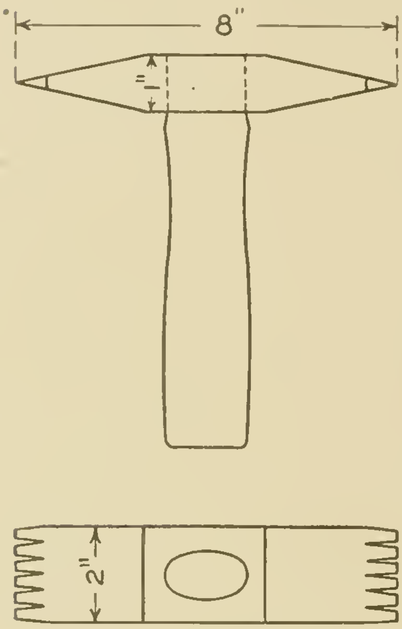


Fig. 19. Pick for Facing Concrete.

The number of square feet to be picked per day, depends on the hardness of the concrete. If the picking is performed by hand, it is done by a common laborer; and he is expected to cover, on an average, about 50 square feet per day of ten hours. With a pneumatic tool, a man would cover from 400 to 500 square feet per day.

Several concrete bridges in Philadelphia have been finished according to the following specifications; and their appearance is very satisfactory:

> "Granolithic surfacing, where required, shall be composed of 1 part cement, 2 parts coarse sand or gravel, and 2 parts granolithic grit, made into a stiff mortar. Granolithic grit shall be granite or trap rock, crushed to pass a ¼-inch sieve, and screened of dust. For vertical surfaces, the mixture shall be deposited against the face forms to a minimum thickness of 1 inch, by skilled workmen, as the placing of the concrete proceeds; and it thus forms a part of the body of the work. Care must be taken to prevent the occurrence of air-spaces or voids in the surface. The face shall be removed

as soon as the concrete has sufficiently hardened; and any voids that may appear shall be filled with the mixture. The surface shall then be immediately washed with water until the grit is exposed and rinsed clean, and shall be protected from the sun and kept moist for three days. For bridge-seat courses and other horizontal surfaces, the granolithic mixture shall be deposited on the concrete to at least a thickness of 1½-inches, immediately after the concrete has been tamped and before it has set, and shall be troweled to an even surface, and, after it has set sufficiently hard, shall be washed until the grit is exposed."

A very satisfactory finish for a ten-span reinforced concrete viaduct on the Utica & Mohawk Railway, was produced in the following manner: For a hard wall, the surface was wet, and a thin 1:2 mortar was applied with a brush. The surface was then thoroughly rubbed with a piece of grindstone or carborundum, removing all broad marks and filling all pores, and producing a lather on the surface of the concrete; and before this had time to dry, it was gone over with a brush dipped in water, producing a smooth, even, and uniform color. For a green wall, when the forms were removed in less than seven days, the surface was wet, and a thin grout of pure cement was applied with a brush; the surface was then rubbed with a piece of grindstone or carborundum, and finished in the same manner as above described. This method has been used by other railroad companies also, on similar work; and the results have been found exceedingly satisfactory.

The following method has been adopted by the New York Central Railroad for giving a good finish to exposed concrete surfaces: The forms of 2-inch tongued-and-grooved pine were coated with soft soap, all openings in the joints of the forms being filled with hard soap. The concrete was then deposited, and, as it progressed, was drawn back from the face with a square-pointed shovel, and 1:2 mortar poured in along the forms. When the forms were removed, and while the concrete was green, the surface was rubbed, with a circular motion, with pieces of white firebrick or brick composed of one part cement and one part sand. The surface was then dampened and painted with a 1:1 grout, rubbed in, and finished with a wooden float, leaving a smooth and hard surface when dry.

Floors and walks are often finished with a 1-inch coat of cement and sand, or of cement, sand, and grit, which is usually mixed in the proportions of 1 part cement and 1 part sand, or of 1 part cement, 1 part sand, and 1 part grit. (See Fig. 20.) This finishing coat must be put on before the concrete of the base sets. The cement and sand must be thoroughly mixed while dry, so as to have a uniform color.

In office buildings, and generally in factory buildings, a wooden floor is laid over the concrete. Wooden stringers are first laid on the concrete, about 2 to 2½ feet apart. The stringers are 2 inches thick and 3 inches wide on top, with sloping edges. The space between the stringers is filled with cinder concrete, as shown in Fig. 21, usually mixed 1 : 4 : 8. When the concrete has set, the flooring is nailed to the stringers.

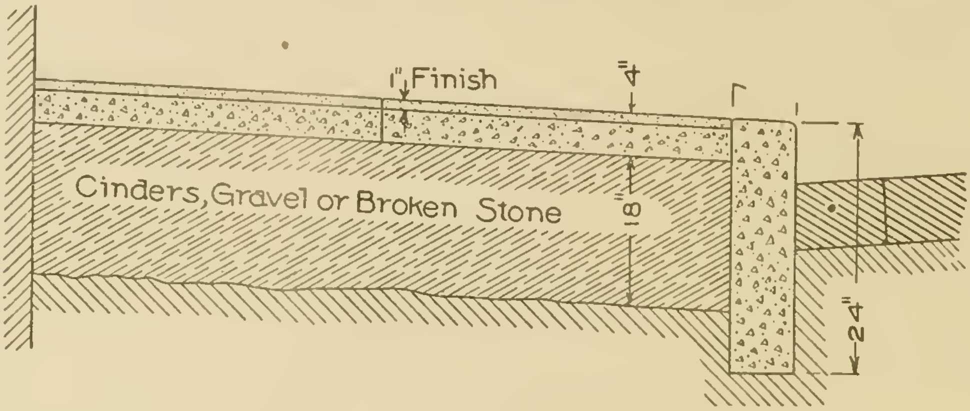


Fig. 20. Concrete Sidewalk and Curb.

The following method of placing mortar facing has been found very satisfactory, and has been adopted very extensively in the last few years: A sheet-iron plate 6 or 8 inches wide and about 5 or 6 feet long, has riveted across it on one side angles of $\frac{3}{4}$-inch size or such other size as may be necessary to give the desired thickness of mortar facing, these angles being spaced about two feet apart. In operation, the ribs of the angles are placed against the forms; and the space between the plate and forms is filled with mortar, which is mixed in small batches, and thoroughly tamped. The concrete back filling is then placed; the mold is withdrawn; and the facing and back filling

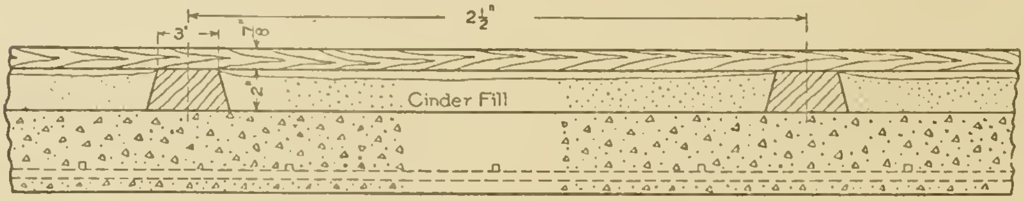


Fig. 21. Cinder Fill Between Stringers.

are rammed together. The mortar facing is mixed in the proportion of one part cement, to 1, 2, or 3 parts sand; usually a 1:2 mixture is employed, mixed wet and in small batches as used. As mortar facing shows the roughness of the forms more readily than concrete does, care is required in constructing, to secure a smooth finish. When the forms are removed, the face may be treated either in the manner already described, or according to the following method taken from the "Proceedings" of the American Railway Engineering and Maintenance of Way Association:

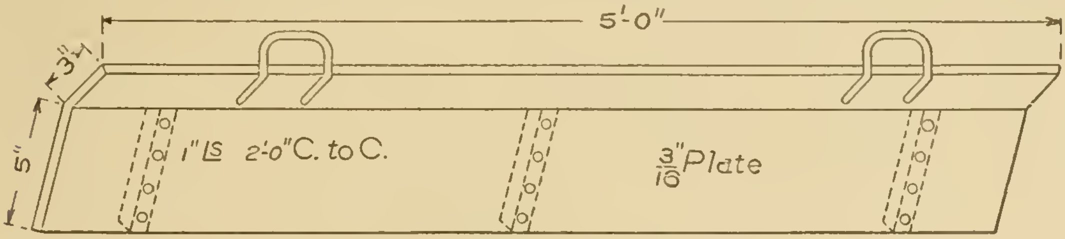


Fig. 22. Mold for Mortar Facing.

> "After the forms are removed, any small cavities or openings in the concrete shall be filled with mortar if necessary. Any ridges due to cracks or joints in the lumber shall be rubbed down; the entire face shall be washed with a thin grout of the consistency of whitewash, mixed in the proportion of 1 part cement to 2 parts of sand. The wash shall be applied with a brush."

Concrete surfaces may be finished to represent ashlar masonry. The process is similar to stone-dressing; and any of the forms of finish employed for cut stone can be used for concrete. Very often, when the surface is finished to represent ashlar masonry, vertical and horizontal three-sided pieces of wood are fastened to the forms to make V-shaped depressions in the concrete, as shown in Fig. 23.

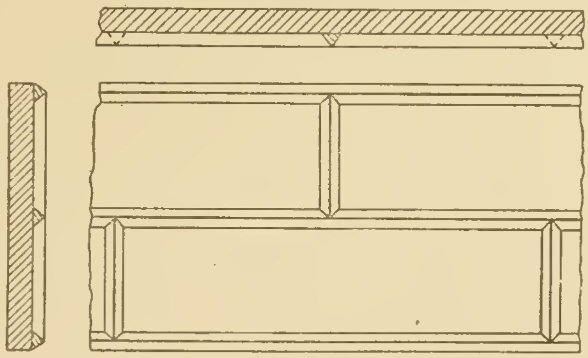


Fig. 23. Concrete Molding.

A facing of stone or brick is frequently used for reinforced concrete, and is a very satisfactory solution of the problem of finish. The same care is required with a stone or brick facing as if the entire structure were stone or brick. The Ingalls Building at Cincinnati, Ohio, 16 stories, is veneered on the outside with marble to a height of three stories, and with brick and terra-cotta above the third story. Exclusive of the facing, the wall is 8 inches thick.

Water-tightness of Concrete. Water-tight concrete, or concrete made water-tight by some kind of waterproof coating, is frequently required, either for inclosing a space which must be kept dry, or for storing water or other liquids.

It is generally considered that in monolithic construction, a wet mixture, a rich concrete, and an aggregate proportioned for great density, are essential for water-tightness. With the wet mixtures of concrete now generally used in engineering work, concrete possesses far greater density, and is correspondingly less porous, than with the older, dryer mixtures. At the same time, in the large masses of actual work, it is difficult to produce concrete of such close texture as to prevent undesirable seepage at all points. Many efforts have been made to secure water-tightness of concrete in a practical manner—some with success, but others with unsatisfactory results. There are now a great many special preparations being advertised for making concrete water-tight.

It has frequently been observed that when concrete was green, there was a considerable seepage through it, and that in a short time absolutely all seepage stopped. Some experiments have been made to render porous concrete impermeable, by forcing water through a rich concrete under pressure. In these experiments, a mixture of 1 part Portland cement to 4 parts crushed gravel was used. The concrete tested was 6 inches thick. The flow through the concrete on the first day of the experiment, under a pressure of 36 pounds per square inch, was taken as 100 per cent. On the forty-sixth day, under a pressure of 48 pounds per square inch, the flow amounted to only 0.7 per cent.

While the pressure was constant, the rate of seepage of the water decreased with the lapse of time, showing a marked tendency of the seepage passages to become closed. The experimenter is of the opinion that the water, under pressure, *dissolves* some of the material and then deposits it in stalactitic form near the exterior surface of the concrete, where the water escapes under much reduced pressure. Others, however, think it quite possible that fine material carried *in suspension* by the water aids in producing the result.

For cistern work, two coats of Portland cement grout—1 part cement, 1 part sand—applied on the inside, have been found sufficient. About one inch of rich mortar has usually been found effective under high pressure. A coating of asphalt, or of asphalt with tarred or asbestos felt, laid in alternate layers between layers of concrete, has been used successfully. Coal-tar pitch and tarred felt, laid in alternate layers, have been used extensively and successfully in New York City for waterproofing.

Mortar may be made practically non-absorbent by the addition of alum and potash soap. One per cent by weight of powdered alum is added to the dry cement and sand, and thoroughly mixed; and about one per cent of any potash soap (ordinary soft soap) is dissolved in the water used in the mortar. A solution consisting of 1 pound of concentrated lye, 5 pounds of alum, and 2 gallons of water, applied while the concrete is green and until it lathers freely, has been successfully used. Coating the surface with boiled linseed oil until the oil ceases to be absorbed, is another method that has been used with success.

A reinforced concrete water-tank, 10 feet inside diameter and 43 feet high, designed and constructed by W. B. Fuller at Little Falls, N. J., has some remarkable features. It is 15 inches thick at the bottom and 10 inches thick at the top. The tank was built in eight hours, and is a perfect monolith, all concrete being dropped from the top, or 43 feet at the beginning of the work. The concrete was mixed very wet, the mixture being 1 part cement, 3 parts sand, and 7 parts broken stone. No plastering or waterproofing of any kind was used, but the tank was found to be absolutely water-tight, although the mixture used has not generally been found or considered water-tight.

At Attleboro, Mass., a large reinforced concrete standpipe, 50 feet in diameter, 106 feet high from the inside of the bottom to the top of the cornice, and with a capacity of 1,500,000 gallons, has been constructed, and is in the service of the water works of that city. The walls of the standpipe are 18 inches thick at the bottom, and 8 inches thick at the top. A mixture of 1 part cement, 2 parts sand, and 4 parts broken stone, the stone varying from $\frac{1}{4}$ inch to $1\frac{1}{2}$ inches, was used. The forms were constructed, and the concrete placed, in sections of 7 feet. When the walls of the tank had been completed, there was some leakage at the bottom with a head of water of 100 feet. The inside walls were then thoroughly cleaned and picked, and four coats of plaster applied. The first coat contained 2 per cent of lime to 1 part of cement and 1 part of sand; the remaining hree coats were composed of 1 part sand to 1 part cement. Each coat was floated until a hard, dense surface was produced; then it was scratched to receive the succeeding coat.

On filling the standpipe after the four coats of plaster had been applied, the standpipe was found to be not absolutely water-tight. The water was drawn out; and four coats of a solution of castile soap, and one of alum, were applied alternately; and, under a 100-foot head, only a few leaks then appeared. Practically no leakage occurred at the joints; but in several instances a mixture somewhat wetter than usual was used, with the result that the spading and ramming served to drive the stone to the bottom of the batch being placed, and, as a consequence, in these places porous spots occurred. The joints were obtained by inserting beveled tonguing pieces, and by thoroughly washing the joint and covering it with a layer of thin grout before placing additional concrete.

In the construction of the filter plant at Lancaster, Pa., in 1905, a pure-water basin and several circular tanks were constructed of reinforced concrete. The pure-water basin is 100 feet wide by 200 feet long and 14 feet deep, with buttresses spaced 12 feet 6 inches center to center. The walls at the bottom are 15 inches thick, and 12 inches thick at the top. Four circular tanks are 50 feet in diameter and 10 feet high, and eight tanks are 10 feet in diameter and 10 feet high. The walls are 10 inches thick at the bottom, and 6 inches at the top. A wet mixture of 1 part cement, 3 parts sand, and 5 parts stone, was used. No waterproofing material was used, and the basin and tanks are water-tight.

Forms. In actual construction work, the cost of forms is a large item of expense, and offers the best field for the exercise of ingenuity. For economical work, the design should consist of a repetition of identical units; and the forms should be so devised that it will require a minimum of nailing to hold them, and of labor to make and handle them. Forms are constructed of the cheaper grades of lumber. To secure a smooth surface, the planks are planed on the side on which the concrete will be placed. Green lumber is preferable to dry, as it is less affected by wet concrete. If the surface of the planks that are placed next to the concrete are well oiled, the planks can be taken down much easier, and, if they are kept from the sun, can be used several times.

Crude oil is an excellent and cheap material for greasing forms, and can be applied with a white-wash brush. The oil should be applied every time the forms are used. The object is to fill the pores of the wood, rather than to cover it with a film of grease. Thin soft soap, or a paste made from soap and water, is also sometimes used.

In constructing a factory building of two or three stories, usually the same set of forms are used for the different floors; but when the building is more than four stories high, two or more sets of forms are specified, so as always to have one set of forms ready to move.

The forms should be so tight as to prevent the water and thin mortar from running through, and thus carrying off the cement. This is accomplished by means of tongued-and-grooved or beveled-edge boards; but it is often possible to use square lumber if it is thoroughly wet so as to swell it before the concrete is placed. The beveled-edge boards are often preferred to tongue-and-grooved boards, as the edges tend to crush as the boards swell, and this prevents buckling.

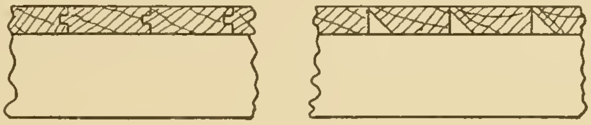


Fig. 24. Tongued and Grooved Edge.

Beveled Edge

Lumber for forms may be made of 1-inch, $1\frac{1}{2}$-inch, or 2-inch plank. The spacing of studs depends in part upon the thickness of concrete to be supported, and upon the thickness of the boards on which the concrete is placed. The size of the studding depends upon the height of the wall and the amount of bracing used. Except in very heavy or high walls, 2 by 4-inch or 2 by 6-inch studs are used. For ordinary floors with 1-inch plank, the supports should be placed about 2 feet apart; with $1\frac{1}{2}$-inch plank, about 3 feet apart; and 2-inch plank, 4 feet apart.

The length of time required for concrete to set depends upon the weather, the consistency of the concrete, and the strain which is to come on it. In good drying weather, and for very light work, it is often possible to remove the forms in 12 to 24 hours after placing the concrete, if there is no load placed on it. The setting of concrete is greatly retarded by cold or wet weather. Forms for concrete arches and beams must be left in place longer than in wall work, because of the tendency to fail by rupture across the arch or beam. In small, circular arches, like sewers, the forms may be removed in 18 to 24 hours if the concrete is mixed dry; but if wet concrete is used, in 24 to 48 hours. Forms for large arch culverts and arch bridges are seldom taken down in less than 14 days; and it is often specified that they must not be struck for 28 days after placing the last concrete. In ordinary floor construction, consisting of slabs, girders, and beams, the forms are usually left in place at least a week.

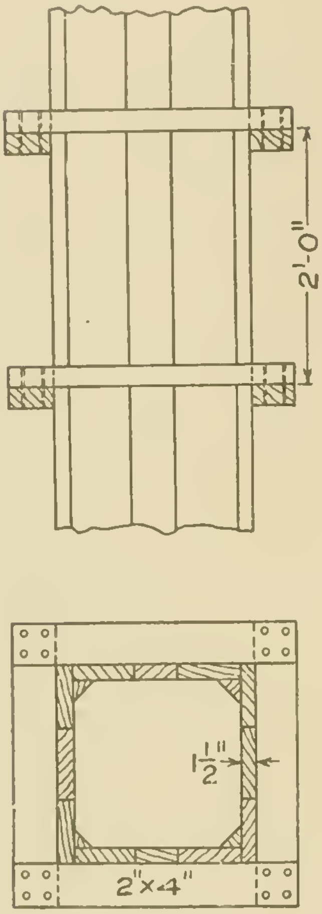


Fig. 25. Forms for Columns.

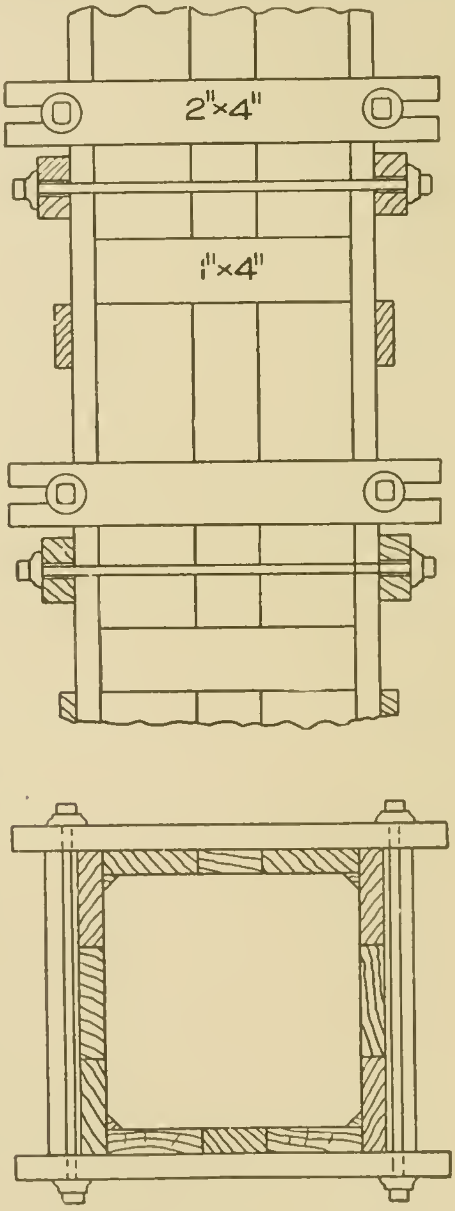


Fig. 26. Forms for Columns.

In constructing columns, the forms are usually erected complete, the full height of the column, and concrete is dumped in at the top. The concrete must be mixed very wet, as it cannot be rammed very thoroughly at the bottom, and care must be taken not to displace the steel. Sometimes the forms are constructed in short sections, and the concrete is placed and rammed as the forms are built. The ends of the bottom of the forms for the girders and beams, are usually supported by the column forms. To give a beveled edge to the corner of the columns, a triangular strip is fastened in the corner of the forms.

Fig. 25 shows the common way, or some modification of it, of constructing forms for column. The plank may be 1 inch, 1½ inches, or 2 inches thick; and the cleats are usually 1 by 4 inches and 2 by 4 inches. The spacing of the cleats depends on the size of the columns and the thickness of the vertical plank.

Fig. 26 shows column forms similar to those used in constructing the Harvard stadium. The planks forming each side of the column are fastened together by cleats, and then the four sides are fastened together by slotted cleats and steel tie-rods. These forms can be quickly and easily removed.

Fig. 27 shows column forms in which the concrete is placed and rammed as the forms are constructed. Three sides are erected to the full height, and the steel is then placed. The fourth side is built up with horizontal boards as the concrete is placed and rammed.

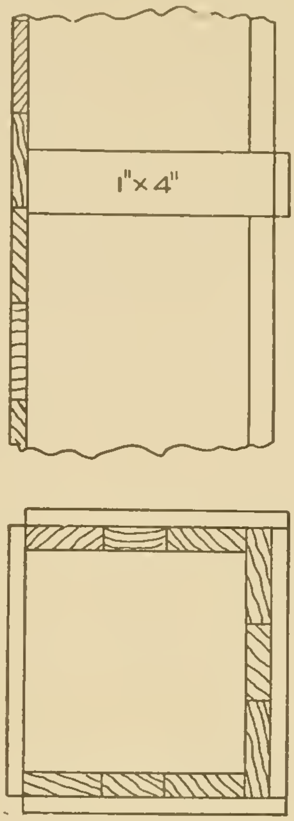


Fig. 27. Forms for Columns.

A very common style of forms for beam and slab construction is shown in Fig. 28. The size of the different members of the forms

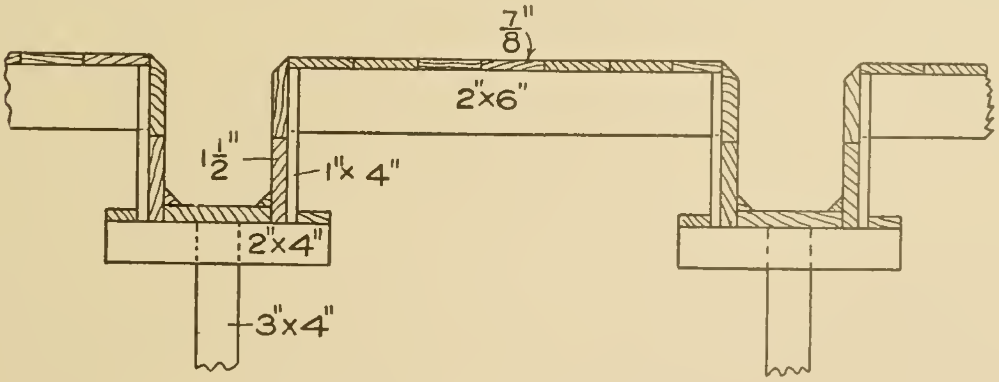


Fig. 28. Forms for Beams and Slabs.

depends upon the size of the beams, the thickness of the slabs, and the relative spacing of some of the members. If the beam is

10 by 20 inches, and the slab is 4 inches thick, then 1-inch plank supported by 2 by 6-inch timbers spaced 2 feet apart, will support the slab. The sides and bottom of the beams are enclosed by 1½-inch or 2-inch plank supported by 3 by 4-inch posts spaced 4 feet apart.

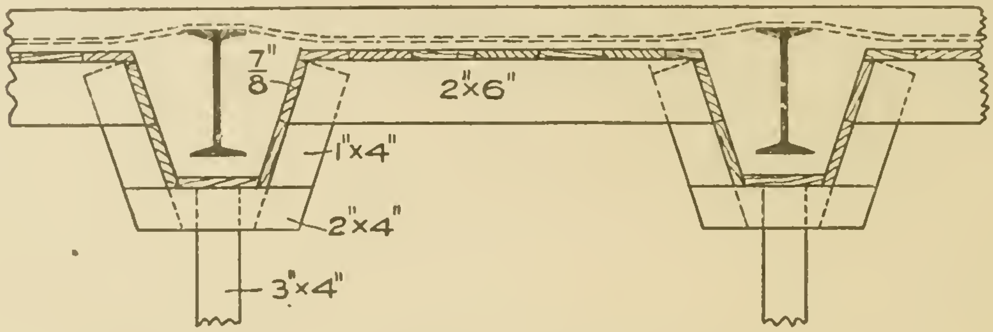


Fig. 29. Forms for Reinforced Concrete Slab Supported by I-beams.

In Fig. 29 is shown the forms for a reinforced concrete slab, with I-beam construction. These forms are constructed similarly to those just described.

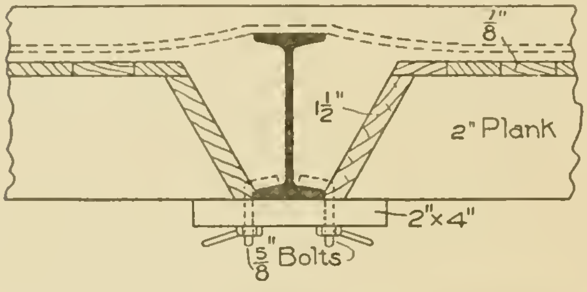


Fig. 30. Form for Reinforced Concrete Slab between I-beams.

A slab construction, supported on I-beams, the bottom of which is not covered with concrete, may have forms constructed as shown in Fig. 30. This method of constructing forms was designed by Mr. William F. Kearns (Taylor & Thompson, "Plain and Reinforced Concrete").

The construction of forms for a slab that is supported on the top of I-beams, is a comparatively simple process, as shown in Fig. 31. In any form of I-beam and slab construction, the forms can be constructed to carry the combined weight of the concrete and forms. When the bottom of the I-beam is to be covered with concrete, it is not so easily done as when the haunch rests on the bottom flange (Fig. 30) or is a flat plate (Fig. 31).

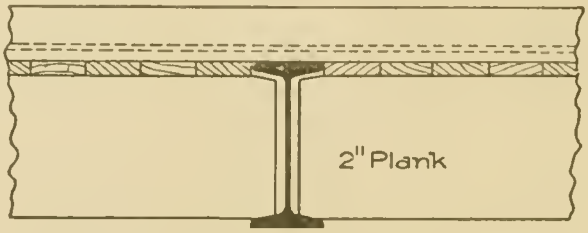


Fig. 31. Form for Floor Slab on I-beams.

Forms for conduits and sewers must be strong enough not to give way under, or to become deformed, while the concrete is being placed and rammed, and must be rigid enough not to warp from being alternately wet and dry. They must be constructed so that they can readily be put up and taken down and can be used several times on the same job. The forms must give a smooth and even finish to the interior of the sewer or conduit. This has been accomplished on several jobs by covering the forms with lightweight sheet iron.

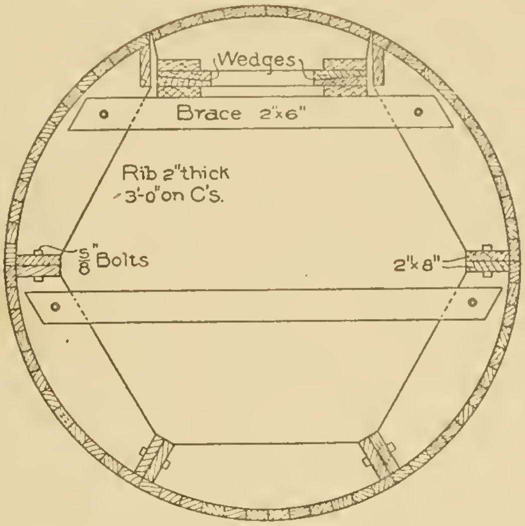
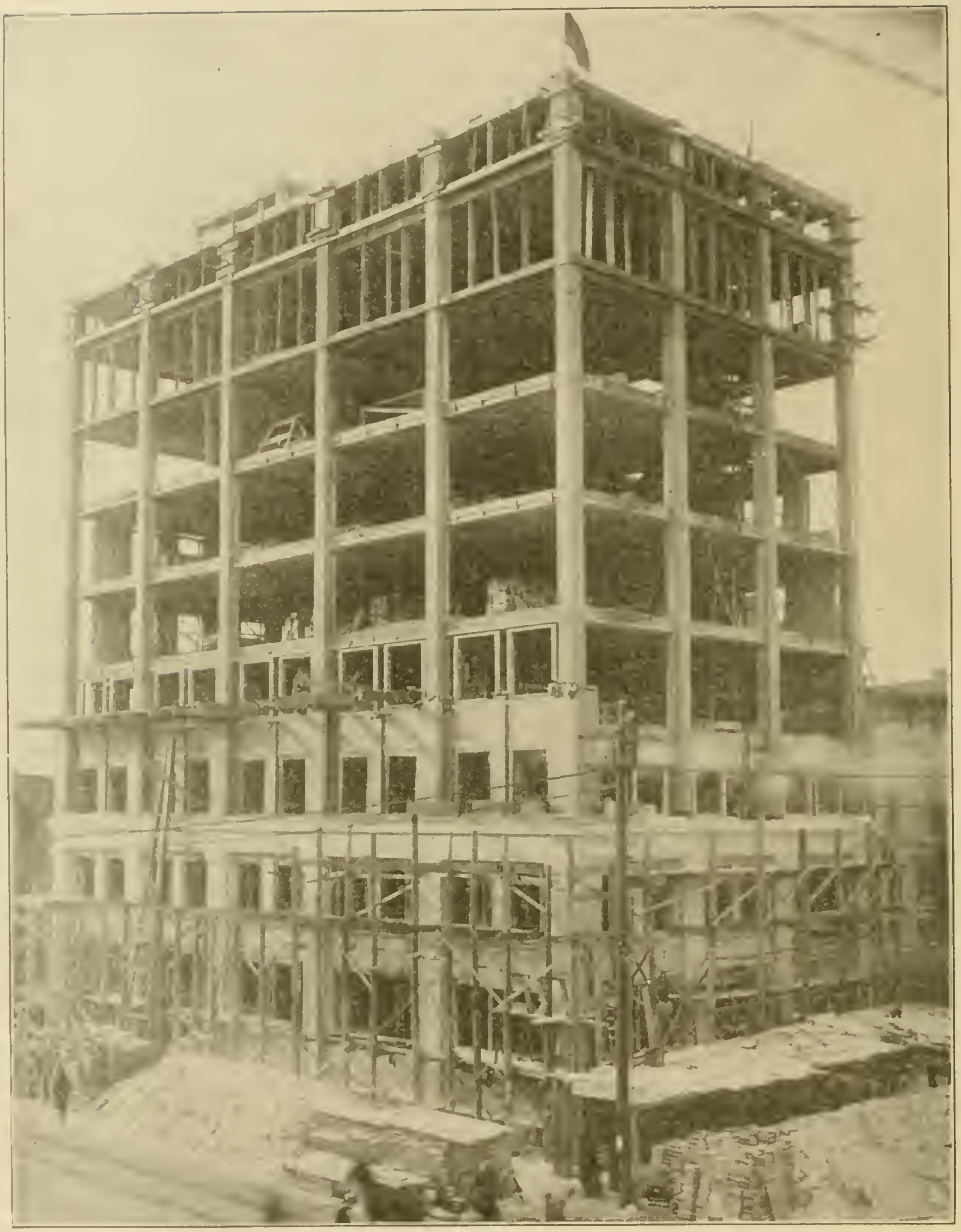


Fig. 32. Center for 8-ft. Sewer.

These forms are usually built in lengths of 16 feet, with one center at each end, and with three to five (depending on the size of the sewer or conduit) intermediate centers in the lengths of 15 feet. The segmental ribs are bolted together. The plank for these forms are made of 2 by 4-inch material, surfaced on the outer side, with the edge beveled to the radius of the conduit. The segmental ribs are bolted together, and are held in place by wooden ties 2 by 4 inches or 2 by 6 inches.



KALAMAZOO NATIONAL BANK, KALAMAZOO, MICH.

J. C. Llewellyn, Architect, Chicago, Ill.

Reinforced Concrete Floors; Steel Columns Reinforced with Concrete. First Two Stories, Buff Bedford Stone; Upper Stories, Pressed Brick. Built in 1907.

REINFORCED CONCRETE

PART II

GENERAL THEORY OF FLEXURE IN REINFORCED CONCRETE

Introduction. The theory of flexure in reinforced concrete is exceptionally complicated. A multitude of simple rules, formulæ, and tables for designing reinforced concrete work have been proposed, some of which are sufficiently accurate and applicable *under certain conditions.* But the effect of these various conditions should be thoroughly understood. Reinforced concrete should not be designed by "rule-of-thumb" engineers. It is hardly too strong a statement to say that a man is criminally careless and negligent when he attempts to design a structure on which the safety and lives of people will depend, without thoroughly understanding the theory on which any formula he may use is based. The applicability of all formulæ is so dependent on the quality of the steel and of the concrete, and on many of the details of the design, that a blind application of a formula is very unsafe. Although the greatest pains will be taken to make the following demonstration as clear and plain as possible, it will be necessary to employ symbols, and to work out several algebraic formulæ on which the rules for designing will be based. The full significance of many of the terms mentioned below may not be fully understood until several subsequent paragraphs have been studied:

b = Breadth of concrete beam;
d = Depth from compression face to center of gravity of the steel;
A = Area of the steel;
p = Ratio of area of steel to area of concrete above the center of gravity of the steel, generally referred to as "percentage of reinforcement,"

$$= \frac{A}{b\,d};$$

E_s = Modulus of elasticity of steel;
E_c = *Initial* modulus of elasticity of concrete;

$r = \frac{E_s}{E_c}$ = Ratio of the moduli;

s = Tensile stress per unit of area in steel;

c = Compressive stress per unit of area in concrete at the outer fiber of the beam; this may vary from zero to c';
c' = Ultimate compressive stress per unit of area in concrete — the stress at which failure might be expected;
ϵ_s = Deformation per unit of length in the steel;
ϵ_c = " " " " " in outer fiber of concrete;
ϵ'_c = " " " " " in outer fiber of concrete when crushing is imminent;
ϵ''_c = Deformation per unit of length in outer fiber of concrete under a certain condition (described later);

$q = \frac{\epsilon_c}{\epsilon_c''}$ = Ratio of deformations;

k = Ratio of depth from compressive face to the neutral axis to the total effective depth d;
x = Distance from compressive face to center of gravity of compressive stresses;
ΣX = Summation of horizontal compressive stresses;
M = Resisting moment of a section.

Statics of Plain Homogeneous Beams. As a preliminary to the theory of the use of reinforced concrete in beams, a very brief discussion will be given of the statics of an ordinary homogeneous beam. Let A B represent a beam carrying a uniformly distributed load W; then the beam is subjected to transverse stresses. Let us imagine that *one-half* of the beam is a "free body" in space and is acted on by exactly the same external forces; we shall also assume the forces C and T (acting on the exposed section), which are just such forces as are required to keep that half of the beam in equilibrium.

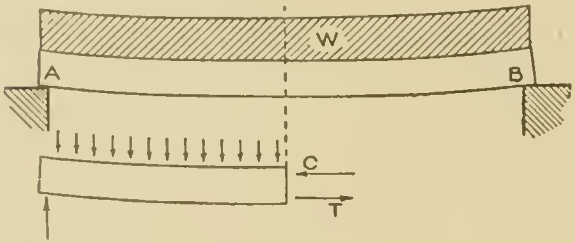


Fig. 33.

These forces, and their direction, are represented in the lower diagram by arrows. The load W is represented by the series of small, equal, and equally spaced vertical arrows pointing downward. The reaction of the abutment *against the beam* is an *upward* force, shown at the left. The forces acting on a *section* at the center are the equivalent of the two equal forces C and T.

The force C, acting at the top of the section, must act toward the left, and there is therefore compression in that part of the section. Similarly, the force T is a force acting toward the right, and the fibers of the lower part of the beam are in tension. For our present purpose we may consider that the forces C and T are in each case the resultant of the forces acting on a very large number of "fibers." The stress in the outer fibers is of course greatest. At the center of the height there is neither tension nor compression. This is called the "neutral axis."

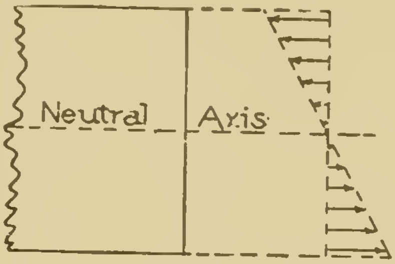


Fig. 34.

Let us consider for simplicity a very narrow portion of the beam, having the full length and depth, but so narrow that it includes only one set of fibers, one above the other, as shown in Fig. 35. In the case of a plain, rectangular, homogeneous beam, the stresses in the fibers would be as given in Fig. 34; the neutral axis would be at the center of the height, and the stress at the bottom and the top would be equal but opposite. If the section were at the center of the beam, with a uniformly distributed load (as indicated in Fig. 33), the "shear" would be zero. These general principles have already been explained in "Strength of Materials," sections 57-60.

A beam *may* be constructed of plain concrete; but its strength will be very small, since the tensile strength of concrete is comparatively insignificant. Reinforced concrete utilizes the great tensile strength of steel, in combination with the compressive strength of concrete. It should be realized that the essential qualities are *compression* and *tension*, and that (other things being equal) the cheapest method of obtaining the necessary compression and tension is the most economical.

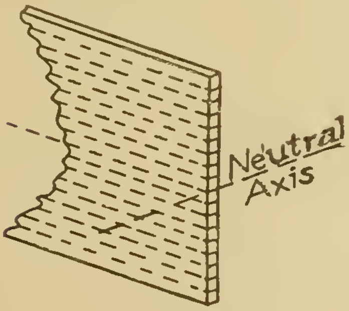


Fig. 35.

Economy of Concrete for Compression. The ultimate compressive strength of concrete is generally 2,000 pounds or over per square inch. With a factor of safety of four, a working stress of 500 pounds per square inch may be considered allowable. We may estimate that the concrete costs twenty cents per cubic foot, or $5.40 per cubic yard. On the other hand, we may estimate that the steel, placed in the work, costs about three cents per pound. It will weigh 480 pounds per cubic foot; therefore the steel costs $14.40 per cubic foot, or 72 times as much as an equal *volume* of concrete or an equal *cross-section* per unit of length. But the steel can safely withstand a compressive stress of 16,000 pounds per square inch, which is 32 times the safe working load on concrete. Since, however, a given volume of steel costs 72 times an equal volume of concrete, the cost of a given compressive resistance in steel is $\frac{72}{32}$ (or 2.25) times the cost of that resistance in concrete. Of course, the above assumed unit prices of concrete and steel will vary with circumstances. The advantage of concrete over steel for compression may be somewhat greater or less than the ratio given above, but the advantage is almost invariably with the concrete. There are many other advantages in addition, which will be discussed later.

Economy of Steel for Tension. The ultimate tensile strength of ordinary concrete is rarely more than 200 pounds per square inch. With a factor of safety of four, this would allow a working stress of only 50 pounds per square inch. This is generally too small for practical use, and certainly too small for economical use. On the other hand, steel may be used with a working stress of 16,000 pounds per square inch, which is 320 times that allowable for concrete. Using the same unit values for the cost of steel and concrete as given in the previous section, even if steel costs 72 times as much as an equal volume of concrete, its real tensile value economically is $\frac{320}{72}$ (or 4.44) times as great. Any reasonable variation from the above unit values cannot alter the essential truths of the economy of steel for tension and of concrete for compression. In a reinforced concrete beam, the steel is placed in the tension side of the beam. Usually it is placed from one to two inches from the outer face, with the double purpose of protecting the steel from corrosion or fire, and also to better insure the union of the concrete and the steel. But the concrete below the steel is not considered in the numerical calculations. Even the concrete which is between the steel and the neutral axis (whose position will be discussed later), is chiefly useful in transmitting the tension in the steel to the concrete. Although such concrete is theoretically subject to tension, and does actually contribute its share of the tension when the stresses in the beam are small, the proportion of the necessary tension which the concrete can furnish when the beam is heavily loaded, is so very small that it is usually ignored, especially since such a policy is on the side of safety, and also since it greatly simplifies the theoretical calculations and yet makes very little difference in the final result. We may therefore consider that in a unit section of the beam, as in Fig. 36, the concrete above the neutral axis is subject to compression, and that the tension is furnished entirely by the steel.

Elasticity of Concrete in Compression. In computing the transverse stresses in a wooden beam or steel I-beam, it is assumed that the modulus of elasticity is uniform for all stresses within the elastic limit. Experimental tests have shown this to be so nearly true that it is accepted as a mechanical law. This means that if a force of 1,000 pounds is required to stretch a bar .001 of an inch, it will require 2,000 pounds to stretch it .002 of an inch. Similar tests have been made with concrete, to determine the law of its elasticity. Unfortunately, concrete is not so uniform in its behavior as steel. The results of tests are somewhat contradictory. Many engineers have argued that the elasticity is so nearly uniform that it may be considered to be such within the limits of practical use. But all experimenters who have tested concrete by measuring the proportional compression produced by various pressures, agree that the additional shortening produced by an additional pressure of say 100 pounds per square inch, is greater at higher pressures than at low pressures.

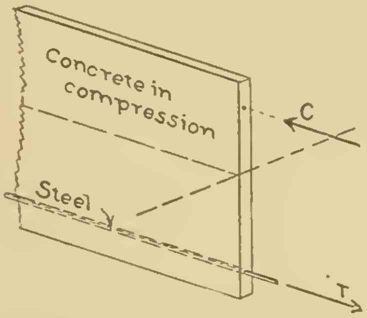


Fig. 36. Transmission of Tension in Steel to Concrete.

A test of this sort may be made substantially as follows: A square or circular column of concrete at least one foot long is placed in a testing machine. A very delicate micrometer mechanism is fastened to the concrete by pointed screws of hardened steel. These points are originally at a known distance apart—say 8 inches. When the concrete is compressed, the distance between these points will be slightly less. A very delicate mechanism will permit this distance to be measured as closely as the ten-thousandth part of an inch or, to about $\frac{1}{100,000}$ of the length. Suppose that the various pressures per square inch, and the proportionate compressions, are as given in the following tabular form:

Pressure per Square Inch	Proportionate Compression
200 pounds	.00010 of total length
400 "	.00020 " " "
600 "	00032 " " "
800 "	.00045 " " "
1,000 "	.00058 " " "
1,200 "	.00062 " " "
1,400 "	.00090 " " "
1,600 "	.00112 " " "

We may plot these pressures and compressions as in Fig. 37, using any convenient scale for each. For example, for a pressure of 800 pounds per square inch, we select the vertical line which is at the horizontal distance from the origin *O* of 800, according to the scale adopted. Scaling off on this vertical line the ordinate .00045, according to the scale adopted for compressions, we have the position of one point of the curve. The other points are obtained similarly. Although the points thus obtained from the testing of a single block of concrete would not be considered sufficient to establish the law of the elasticity of concrete in compression, a study of the curves which may be drawn through the series of points obtained for each of a large number of blocks, shows that these curves will average very closely to parabolas that are tangent to the initial modulus of elasticity, which is here represented in the diagram by a straight line running diagonally across the figure.

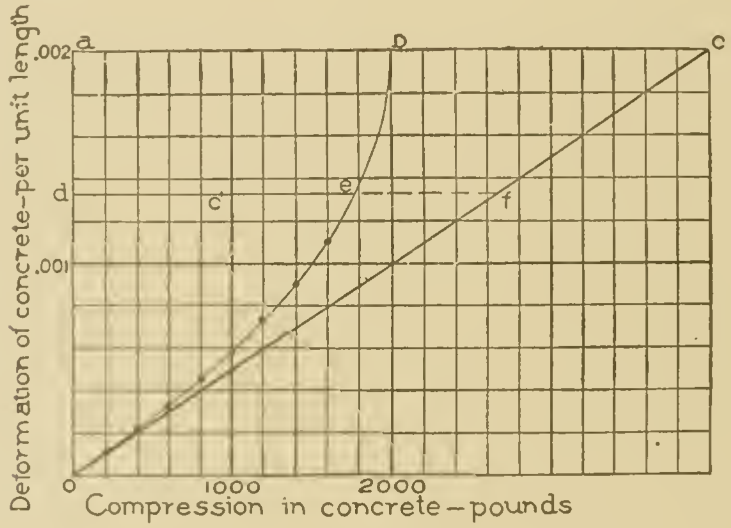


Fig. 37.

It is generally considered that the axis of the parabola will be a horizontal line when the curve is plotted according to this method. The position of the vertex of the parabola cannot be considered as definitely settled. Professor Talbot has computed the curve as if the vertex were at the point of the ultimate compression of the concrete, although he conceded that the vertex might be in an imaginary position corresponding to a compression in the concrete higher than that which the concrete could really endure. Mr. A. L. Johnson, another noted authority, bases his computation of formulæ on the assumption that the ultimate compressive strength of the concrete is two-thirds of the value which would be required to produce that amount of compression, in case the initial modulus of elasticity was the true value for all compressions. In other words, looking at Fig. 37, if *o c* is a line representing the initial modulus of elasticity, then, if the elasticity were uniform throughout, it would require a force of about 2,340 pounds (or *d f*) to produce a proportionate compression of .00132 of the length (represented by *o d*). Actually that compression will be produced when the pressure equals *d e*, which is $\frac{2}{3}$ of *d f*. It should not be forgotten that the above numerical values are given merely for illustrative purposes. They would, if true, represent a rather weak concrete. The following theory is therefore based on the assumption that the stress-strain curve is represented by the parabolic curve *o e* (see Fig. 37); and that the ultimate stress per square inch in the concrete c' is represented by *d e*, which is $\frac{2}{3}$ of the compressive stress that would be required to produce that proportionate compression if the modulus of elasticity of the concrete were uniformly maintained at the value it has for very low pressures.

Theoretical Assumptions. The theory of reinforced concrete beams is based on the usual assumptions that,

(*a*) The loads are applied at right angles to the axis of the beam. The usual vertical gravity loads supported by a horizontal beam, fulfil this condition.

(*b*) There is no resistance to free horizontal motion. This condition is seldom if ever exactly fulfilled in practice. The more rigidly the beam is held at the ends, the greater will be its strength above that computed by the simple theory. Under ordinary conditions the added strength is quite indeterminate; and is not allowed for, except in the appreciation that it adds indefinitely to the safety.

(*c*) The concrete and steel stretch together without breaking the bond between them. This is absolutely essential.

(*d*) Any section of the beam which is plane before bending is plane after bending.

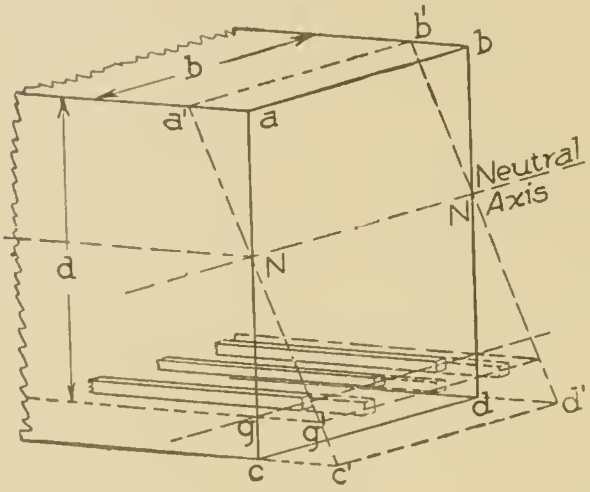


Fig. 38.

In Fig. 38, is shown, in a very exaggerated form, the essential meaning of assumption *d*. The section *a b c d* in the unstrained condition, is changed to the plane *a' b' c' d'* when the load is applied. The compression at the top = *a a'* = *b b'*. The neutral axis is unchanged. The concrete at the bottom is stretched an amount = *c c'* = *d d'*, while the stretch in the steel equals *g g'*. The compression in the concrete between the neutral axis and the top is proportional to the distance from the neutral axis.

In Fig. 39*a*, is given a side view of the beam, with special reference to the deformation of the fibers. Since the fibers between the neutral axis and the compressive face are compressed proportionally, then, if *a a'* represents the lineal compression of the outer fiber, the shaded lines represent, at the same scale, the compression of the intermediate fibers.

In Fig. 39*b*, *m n* indicates the stress there would be in the outer fiber if the initial modulus of elasticity applied to all stresses. But since the force required to produce the compression *a a'* is *proportionately* so much less than that required for the lesser compressions, the actual pressure in pounds on the outer fiber may be represented by a line *v n*, and the pressure on the intermediate fibers by the ordinates to the curve *v N*.

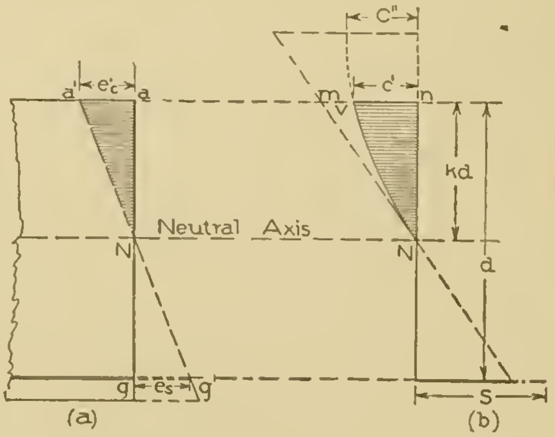


Fig. 39.

In Fig. 40, *a* and *b*, are shown a pair of figures corresponding with those of Fig. 39, except that the compressive deformation of the concrete in the outer fiber $a\ a'$ is only *one-half* of the value in Fig. 39. But it will require about three-fourths as much pressure to produce one-half as much compression. In Fig. 40, $v'\ n'$ is therefore three-fourths of $v\ n$ in Fig. 39. The student should note that k' here differs slightly from k, which means that the position of the neutral axis varies with the conditions.

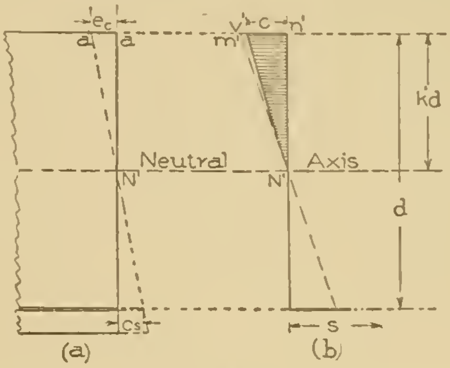


Fig. 40.

Summation of the Compressive Forces. The summation of the compressive forces is evidently indicated by the area of the shaded portion in Fig. 41. The curve $v\ N$ is a portion of a parabola. The area of the shaded portion between the curve $v\ N$ and the straight line $v\ N$, equals one-third of the area of the triangle $m\ N\ v$. The area of the triangle $v\ n\ N = \frac{1}{2}\ c\ kd$. Therefore, for the total shaded area, we have

$$\text{Area} = \tfrac{1}{2}\ c\ kd + \tfrac{1}{3}\ (c_o - c)\ \tfrac{1}{2}\ kd,$$
$$= \tfrac{1}{2}\ kd\ (c + \tfrac{1}{3}\ c_o - \tfrac{1}{3}\ c),$$
$$= \tfrac{1}{2}\ kd\ (\tfrac{2}{3}\ c + \tfrac{1}{3}\ c_o).$$

But in this case, $c_o = E_c\ \epsilon_c$; therefore

$$\text{Area} = \tfrac{1}{2}\ kd\ (\tfrac{2}{3}\ c + \tfrac{1}{3}\ E_c \epsilon_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

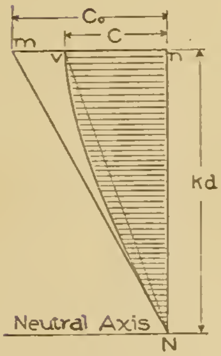


Fig. 41.

In Fig. 42 has been redrawn the parabola of Fig 37, in which *o* is the vertex of the parabola. Here c'' is the force which would produce a compression of ϵ_c'' provided the concrete could endure such a pressure without rupture. If the initial modulus of elasticity applied to all stresses, the required force would be the line $E_c\ \epsilon_c''$. And $c'' = \frac{1}{2}\ E_c\ \epsilon_c''$.

It is one of the well-known properties of the parabola that abscissas are proportional to the squares of the ordinates, or that (in this case),

$$k\ l : m\ n :: \overline{o\ k}^2 : \overline{o\ m}^2$$

Transforming to the symbols, we have

$$(c'' - c)\ :\ c''\ :: (\epsilon_c'' - \epsilon_c)^2\ :\ \epsilon_c''^2\ ;$$

$$(c'' - c) = c'' \frac{(\epsilon_c'' - \epsilon_c)^2}{\epsilon_c''^2}$$

$$c'' - c = c''(1 - q)^2, \text{ since } \frac{\epsilon_c}{\epsilon_c''} = q.$$

$$\begin{aligned} c &= c''\left\{1 - (1 - q)^2\right\}; \\ &= c''(2q - q^2); \\ &= \tfrac{1}{2} E_c\, \epsilon_c''(2q - 2q^2), \text{ since } c'' = \tfrac{1}{2} E_c\, \epsilon_c''; \text{ and also, since } \epsilon_c'' = \frac{\epsilon_c}{q} \\ &= E_c\, \epsilon_c\,(1 - \tfrac{1}{2}q) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2) \end{aligned}$$

Substituting this value of c in Equation (1), we have:

$$\begin{aligned} \text{Area} &= \tfrac{1}{2} k\, d\left\{\tfrac{2}{3} E_c\, \epsilon_c\,(1 - \tfrac{1}{2} q) + \tfrac{1}{3} E_c\, \epsilon_c\right\} \\ &= \tfrac{1}{2} k\, d\left\{E_c\, \epsilon_c\,(1 - \tfrac{1}{3} q)\right\}. \end{aligned}$$

The summation of the horizontal forces (Σ X) within the shaded area, is evidently expressed by the above "area" multiplied by the breadth of the beam "b." Therefore,

$$\Sigma X = \tfrac{1}{2}(1 - \tfrac{1}{3}q)\, E_c\, \epsilon_c\, b\, k d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

In order to avoid the complication resulting from the attempt to develop formulæ which are applicable to all kinds of assumptions, it will be at once assumed, as previously referred to, that the ultimate compressive strength of the concrete is $\frac{2}{3}$ of the value which would be required to produce that amount of compression in case the initial modulus of elasticity was the true value for all compressions. The practical result of this assumption is that we should always use *ultimate* values for the unit stresses in the steel and the concrete, and also that q will have the constant value of $\frac{2}{3}$.

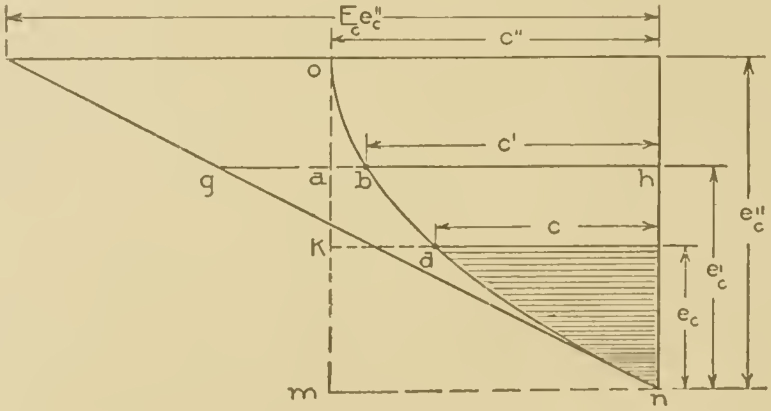


Fig. 42.

The proof that q will equal $\frac{2}{3}$ under these conditions, is perhaps determined most easily by computing the ratio of $b\,h$ to $g\,h$ (see Fig. 42) when $o\,a$ is *assumed* to be $\frac{1}{3}$ of $o\,m$. In this case, from the properties of the parabola, $a\,b = \frac{1}{9}\,m\,n$; $c' = \frac{8}{9}\,m\,n = \frac{8}{9}\,c'' = \frac{4}{9}\,E_c\,\epsilon_c''$.

But when $o\,a = \frac{1}{3}$ of om, $g\,h = \frac{2}{3}\,E_c\epsilon_c = \frac{6}{9}\,E_c\epsilon_c''$.

Therefore $c' = \frac{2}{3}\,g\,h$. But when $o\,a = \frac{1}{3}$ of $o\,m$, $\frac{\epsilon_c'}{\epsilon_c''} = \frac{2}{3}$.

Therefore when $c' = \frac{2}{3}\,gh$, $q = \frac{2}{3}$.

It has already been shown that $c'' = \frac{1}{2}\,E_c\,\epsilon_c''$, and also that $\epsilon_c'' = \frac{\epsilon_c}{q}$. Therefore $\frac{1}{2}\,E_c\,\epsilon_c = c''q$. It has also been shown that $c' = \frac{8}{9}\,c''$, or that $c'' = \frac{9}{8}c'$. Therefore $\frac{1}{2}\,E_c\,\epsilon_c = \frac{9}{8}\,c'q$.

Substituting this value in Equation 3, we have for the summation of the compressive forces above the neutral axis under such conditions:

$$\Sigma X = \tfrac{9}{8}\,(1 - \tfrac{1}{3}\,q)\,q\,c'b\,kd \ldots\ldots (4)$$

Substituting the further condition that $q = \frac{2}{3}$, we have

$$\Sigma X = \tfrac{7}{12}\,c'b\,kd \ldots\ldots (5)$$

Center of Gravity of Compressive Forces. This is also called the *centroid of compression*. The theoretical determination of this center of gravity is virtually the same as the determination of the center of gravity of the shaded area shown in Figs. 40 and 41. The general method of determining this center of gravity requires the use of differential calculus, and is a very long and tedious calculation. But the final result may be reduced to a surprisingly simple form, as expressed in the following equation:

$$x = kd\,\frac{4 - q}{12 - 4q}.$$

Assuming, as explained above, the value of $q = \frac{2}{3}$, this reduces to

$$x = .357\,kd \ldots\ldots (6)$$

When q equals zero, the value of x equals $.333\,kd$; and, at the other extreme when $q = 1$, $x = .375\,kd$.

There is, therefore, a very small range of inaccuracy in adopting the value of $q = \frac{2}{3}$ for *all* computations.

Position of the Neutral Axis. According to one of the fundamental laws of mechanics, the sum of the horizontal tensile forces must be equal and opposite to the sum of the compressive forces. Ignoring the very small amount of tension furnished by the concrete below the neutral axis, the tension in the steel $= A\,s = p\,b\,d\,s =$ the total compression in the concrete. Therefore,

$$p\,b\,d\,s = \tfrac{1}{2}\,(1 - \tfrac{1}{3}\,q)\,E_c\ \epsilon_c\,k\,b\,d.$$

But $s = E_s\epsilon_s$; therefore,

$$p\,E_s\epsilon_s = \tfrac{1}{2}\,(1 - \tfrac{1}{3}q)\ E_c\epsilon_c k.$$

But $\frac{E_s}{E_c} = r$, and by proportional triangles, as shown in Fig. 40.

$$\frac{\epsilon_c}{kd} = \frac{\epsilon_s}{d - kd}\,;\ \text{or}\ \epsilon_c = \epsilon_s\ \frac{k}{1 - k}.$$

Making these substitutions, we have:

$$p\,r = \tfrac{1}{2}\,(1 - \tfrac{1}{3}q)\ \frac{k^2}{1 - k}\ \dots\dots\dots\dots\dots\dots\dots(7)$$

Solving this quadratic for k, we have:

$$k = \sqrt{\frac{2\,p\,r}{(1 - \frac{1}{3}q)} + \frac{p^2r^2}{(1 - \frac{1}{3}q)^2}} - \frac{p\,r}{(1 - \frac{1}{3}q)}\ \dots\dots\dots\dots\dots\dots\dots(8)$$

Equation 8 is a perfectly general equation, which depends for its accuracy only on the assumption that the law of compressive stress to compressive strain is represented by a parabola. The equation shows that k, the ratio determining the position of the neutral axis, depends on three variables—namely, the percentage of the steel (p), the ratio of the moduli of elasticities (r), and the ratio of the deformations in the concrete (q). These must all be determined more or less accurately before we can know the position of the neutral axis.

On the other hand, if it were necessary to work out equation 8, as well as many others, for every computation in reinforced concrete, the calculations would be impracticably tedious. Fortunately the extreme range in k for any one ratio of moduli of elasticities, is only a few per cent, even when q varies from 0 to 1. We shall therefore simplify the calculations by using the constant value $q = \frac{2}{3}$, as explained above.

Substituting $q = \frac{2}{3}$ in Equation 8, we have

$$k = \sqrt{\frac{18}{7}\,pr + \frac{81}{49}\,p^2r^2} - \frac{9}{7}\,p\,r\ \dots\dots\dots\dots\dots\dots\dots(9)$$

The various values for the ratio of the moduli of elasticity (r) are discussed in the succeeding section. The values of k for various values of r and p, and for the uniform value of $q = \frac{2}{3}$, have been computed in the following tabular form. Four values have been chosen for r, in conjunction with nine values of p, varying by 0.2 per cent and covering the entire practicable range of p, on the basis of which values k has been worked out in the tabular form. Usually the value of k can be determined directly from the table. By interpolating between two values in the table, any required value within the limits of ordinary practice can be determined with all necessary accuracy.

TABLE VII

Values of k for Various Values of r and p

r	p								
	.020	.018	.016	.014	.012	.010	.008	.006	.004
10	.505	.487	.468	.446	.422	.395	.361	.323	.274
12	.536	.517	.497	.475	.450	.422	.388	.348	.295
20	.623	.604	.583	.561	.535	.505	.465	.422	.362
40	.736	.718	.700	.678	.654	.623	.584	.536	.467

Ratio of Moduli. Theoretically there is an indefinite number of values of r, the ratio of the moduli of elasticity of the steel and the concrete. The modulus for steel is fairly constant at about 29,000,000 or 30,000,000. The value of the *initial* modulus for concrete varies according to the quality of the concrete, from 1,500,000 to 3,000,000 for stone concrete. An average value for cinder concrete is about 750,000. Some experimental values for stone concrete have fallen somewhat lower than 1,500,000, while others have reached 4,000,000 and even more. We may probably use the following values with the constant value of 29,000,000 for the steel.

TABLE VIII

Modulus of Elasticity of Some Grades of Concrete

Kind of Concrete	Mixture	E_c	r
Cinder..................	1:2:5	750,000	40
Broken Stone	1:6:12	1,450,000	20
" "	1:3:6	2,400,000	12
" "	1:2:4	2,900,000	10

The value given above for 1:6:12 concrete is mentioned only because the value $r = 20$ is sometimes used with the weaker grades of concrete, and the value of approximately 1,450,000 for the elasticity of such concrete has been found by experimenters. The use of such a lean concrete is hardly to be recommended, because of its unreliability. Considering the variability in cinder concrete, the even value of $r = 40$ is justifiable rather than the precise value 38.67.

Percentage of Steel. The previous calculations have been made as if the percentage of the steel might be varied almost indefinitely. While there is considerable freedom of choice, there are limitations beyond which it is useless to pass; and there is always a most economical percentage, depending on the conditions. We have already determined that

$$\frac{\epsilon_c}{\epsilon_s} = \frac{k}{1-k}.$$

But $\epsilon_c = \frac{c}{E_c\,(1 - \frac{1}{2}q)}$; and

$\epsilon_s = \frac{s}{E_s}$; therefore,

$$\frac{\epsilon_c}{\epsilon_s} = \frac{c\ E_s}{sE_c\,(1 - \frac{1}{2}q)} = \frac{c\,r}{s\,(1 - \frac{1}{2}q)} = \frac{1}{1-k}.$$

Solving for k, we have:

$$k = \frac{c\,r}{c\,r + s\,(1 - \frac{1}{2}q)}.$$

Using as before the value of $q = \frac{2}{3}$, the equation becomes:

$$k = \frac{c\,r}{c\,r + .667\,s}.$$

Using the same value of q in equation **7**, and solving for p, we have:

$$p\,r = \frac{7\ k^2}{18\,(1 - k)}.$$

Substituting the above value of k in this equation, we have, after considerable reduction:

$$p = \frac{7\,c\ c\,r}{12\,s\,(c\,r + .667s)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(10)}$$

The above equation shows that we cannot select the percentage of steel at random, since it evidently depends on the selected stresses for the steel and concrete, and also on the ratio of their moduli. For example, consider a high-grade concrete (1:2:5) whose modulus of elasticity is considered to be 2,800,000, and which has a limiting compressive stress of 2,700 pounds (c'), which we may consider in conjunction with the limiting stress of 55,000 pounds in the steel. The values of c, s, and r are therefore 27,000, 55,000, and 10.37 respectively. Substituting these values in equation **10**, we compute $p = .012$.

Example. What percentage of steel would be required for ordinary stone concrete, with $r = 12$, $c = 500$, and $s = 16{,}000$? Ans. 0.66 per cent.

Resisting Moment. The moment which resists the action of the external forces is evidently measured by the product of the distance from the center of gravity of the steel to the centroid of compression of the concrete, times the total compression of the concrete, or, otherwise, times the tension in the steel. The compression in the concrete and the tension in the steel are equal, and it is therefore only a matter of convenience to express this product in terms of the tension in the steel. Therefore, adopting the notation already mentioned, we may write the formula:

$$M = A\,s\,(d - x) \qquad \textbf{(11)}$$

But since the computations are frequently made in terms of the dimensions of the concrete and of the percentage of the reinforcing steel, it may be more convenient to write the equation:

$$M = p\,b\,d\,s\,(d - x) \qquad \textbf{(12)}$$

Example 1. What is the resisting moment of a concrete beam made of ordinary 1:3:6 concrete which is 7 inches wide, 10 inches deep to the reinforcement, and which uses 1 per cent of reinforcement?

Answer. We shall assume that the steel is to be used with a working stress of 16,000 pounds per square inch, which means that our resulting resisting moment may be considered as the resisting moment for a working load. If we were to use, say, 55,000 pounds per square inch for the stress in the steel, which should be considered an ultimate value, we should obtain a proportionately larger value for the resisting moment, but it would in that case represent the ultimate resisting moment. The concrete is supposed to have a ratio for the moduli of elasticity (r) equals 12. With 1% reinforcement (or $p = .01$), the value of k is .422. According to equation **6**.

$$x = .357\,kd = .357 \times .422\,d = .151\,d.$$

Therefore,

$$d - x = .849\,d.$$

Therefore,

$$M = .01 \times 7 \times 10 \times 16{,}000 \times .849 \times 10 = 95{,}088 \text{ inch-pounds.}$$

Example 2. What will be the ultimate resisting moment of a 5-inch slab made of a high quality of concrete (1:2:4) using the most economical percentage of steel?

Answer. For this quality of concrete, $r = 10$; the ultimate compressive strength of the concrete is 2,700; and the ultimate tension in the steel is assumed at 55,000. Substituting these values in Equation 10, we find that the economical percentage of steel is 1.21. Interpolating this value of p in Table VII, considering that $r = 10$, we have $k = .424$. Substituting this value of k in Equation 6 we find that $x = .151\ d$. In the case of the 5-inch slab, we shall assume that the center of gravity of the steel is placed 1 inch from the bottom of the slab. Therefore $d = 4$ inches. For a slab of indefinite width, we shall assume that $b = 12$ inches. Therefore our computed value for the ultimate resisting moment, gives the moment of a strip of the slab one foot wide, and the computed amount of the steel is the amount of steel per foot of width of the slab.

Substituting these various values in Equation 12, we find as the value of the ultimate resisting moment:

$$M_o = .0121 \times 12 \times 4 \times 55{,}000 \times .849 \times 4 = 108{,}482 \text{ inch-pounds.}$$

The area of steel required for each foot of width is:

$$A = .0121 \times 12 \times 4 = .5808 \text{ square inch.}$$

This equals .0484 square inch per inch of width. Since a $\frac{1}{2}$-inch square bar has an area of .25 square inch, we may provide the reinforcement by using $\frac{1}{2}$-inch square bars spaced $\frac{.25}{.0484} = 5.17$ inches, or, say, $5\frac{1}{4}$ inches.

Example 3. A very instructive comparison may be made by considering a 5-inch slab with $d = 4$ inches, but made of 1:3:6 concrete. In this case we call $r = 12$; $c = 2{,}000$; and s (as before) $= 55{,}000$. By the same method as before, we obtain $p = .0084$; $k = .395$; and therefore $x = .141\ d$. Substituting these values in Equation 12, we have:

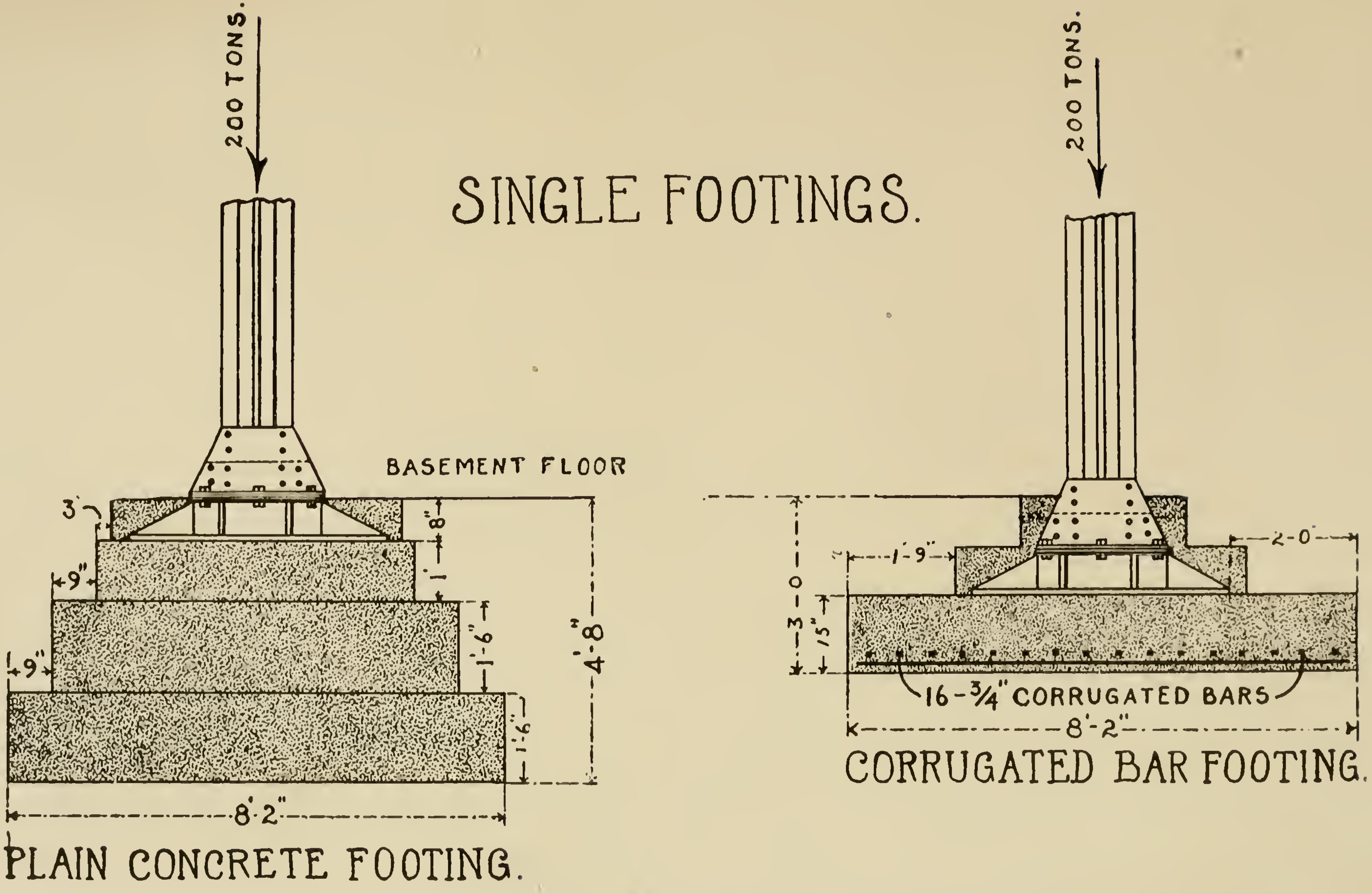
$$M_o = .0084 \times 12 \times 4 \times 55{,}000 \times .859 \times 4 = 76{,}197 \text{ inch-pounds.}$$

The area of steel per foot of width is:

$$A = .0084 \times 12 \times 4 = .4032 \text{ square inch.}$$

This would require $\frac{1}{2}$-inch square bars spaced 7.33 inches. Although the amount of steel required in this slab is considerably less than was required in the previous case, the ultimate moment of the slab is also very much less. In fact the reduction of strength is very nearly in proportion to the reduction in the amount of steel. Therefore, it must be observed that, although the percentage of steel used with high-grade concrete is considerably higher, the thickness of the concrete will be considerably less; and in spite of the fact that the

SINGLE FOOTINGS.



PLAIN CONCRETE FOOTING.

CORRUGATED BAR FOOTING.

COMPARISON BETWEEN PLAIN AND REINFORCED CONCRETE FOOTINGS.

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percentage of steel may be higher, its absolute amount for a slab of equal strength may be approximately the same.

Example 4. Another instructive principle may be learned by determining the required thickness of a slab made of 1:3:6 concrete, which shall have the same ultimate strength as the high-grade concrete mentioned in example 2. In other words, its ultimate moment per foot of width must equal 108,482 inch-pounds. The values of r, c, and s are the same as in example 3, and therefore the value of p must be the same as in example 3; therefore $p = .0084$. Since r and p are the same as in example 3, k again equals .395, and therefore $x = .141\ d$. We therefore have from Equation 12:

$$M_o = 108{,}482 = .0084 \times 12 \times d \times 55{,}000 \times .859 \times d.$$

Solving this equation for d, we find $d^2 = 22.78$; and $d = 4.77$. The area of the steel $A = p\,b\,d = .0084 \times 12 \times 4.77 = .481$. This is considerably less than the area of steel per foot of width as computed in example 2, for a slab of equal strength. On the other hand, the slab of 1:3:6 concrete will require about 15 per cent more concrete. It will also weigh about 10 pounds per square foot more than the thinner slab, which will reduce by that amount the permissible live load. The determination of the relative economy of the two kinds of concrete will therefore depend somewhat on the relative price of the concrete and the steel. The difference in the total cost of the two methods is usually not large; and abnormal variation in the price of cement or steel may be sufficient to turn the scale one way or the other.

Determination of Values for Frequent Use. The above methods of calculation may be somewhat simplified by the determination, once for all, of constants which are in frequent use. For example, a very large amount of work is being done using 1:3:6 concrete. Sometimes Engineers will use the formulæ developed on the basis of 1:3:6 concrete, even when it is known that a richer mixture will be used. Although such a practice is not economical, the error is on the side of safety; and it makes some allowance for the fact that a mixture which is nominally richer *may* not have any greater strength than the values used for the 1:3:6 mixture, on account of defective workmanship or inferior cement or sand. Some of the constants for use with 1:3:6 mixture and 1:2:4 mixture will now be worked out.

For the 1:3:6 mixture, $r = 12$; $c = 2{,}000$; and we shall assume $s = 55{,}000$. On the basis of such values, the economical *percentage* of steel is .84 per cent. Under these conditions, k will always be .395; and x will equal .141 d. Therefore the term $(d - x)$ will always equal .859 d, or say, .86 d, which is close enough for a working value. Since the above values for c and s represent the ultimate values, the resulting moment is the ultimate moment, which we will call M. Therefore, for 1:3:6 concrete, we have the constant values:

$$\begin{aligned} M_o &= .0084 \times b\,d \times 55{,}000 \times .86d \\ &= 397\,b\,d^2 \\ A &= .0084\,b\,d \\ (d\text{-}x) &= .86d \end{aligned} \quad \ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(13)}$$

Similarly we can compute a corresponding value for 1:2:4 concrete, using the values previously allowed for this grade:

$$\begin{aligned} M_o &= .565\,b\,d^2 \\ A &= .0121\,b\,d \\ (d\text{-}x) &= .86d \end{aligned} \quad \ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(14)}$$

Numerical Examples. 1. A flooring with a live load capacity of 150 pounds per square foot, is to be constructed on I-beams spaced 6 feet from center to center, using 1:3:6 concrete. What thickness of slab will be required, and how much steel must be used?

Answer. Using the approximate estimate, based on experience, that such a slab will weigh *about* 50 pounds per square foot, we can compute the ultimate load by multiplying the live load, 150, by four, and the dead load, 50, by two, and obtain a total ultimate load of 700 pounds per square foot. A strip 1 foot wide and 6 feet long (between the beams) will therefore carry a total load of $700 \times 6 = 4{,}200$ pounds. Considering this as a simple beam, we have:

$$M_o = \frac{W_o\,l}{8} = \frac{4{,}200 \times 6 \times 12}{8} = 37{,}800 \text{ inch-pounds.}$$

Placing this numerical value of $M_o = 397\,b\,d^2$, as in Equation **13**, we have $37{,}800 = 397\,b\,d^2$. In this case, $b = 12$ inches. Substituting this value of b, we solve for d^2, and obtain $d^2 = 7.93$, and $d = 2.82$ inches. Allowing an extra inch below the steel, this will allow us to use a 4-inch slab. Theoretically we could make it a little less. Practically this figure should be chosen. The required steel, from

Equation 13, equals .0084 bd. Taking $b = 1$, we have the required steel per *inch* of width of the slab $= .0084 \times 2.82 = .0237$ square inch. If we use ½-inch square bars which have a cross-sectional area of .25 square inch, we may space the bars $\frac{.25}{.0237} = 10$ inches. This reinforcement could also be accomplished by using ⅜-inch square bars, which have an area of .1406. The spacing may therefore be $\frac{.1406}{.0237} = 6.0$ inches. As referred to later, there should also be a few bars laid perpendicular to the main reinforcing bars, or parallel with the I-beams, so as to prevent shrinkage. The required amount of this steel is not readily calculable. Since the I-beams are 6 feet apart, if we place two lines of ⅜-inch square bars spaced 2 feet apart, parallel with the I-beams, there will then be reinforcing steel in a direction parallel with the I-beams at distances apart not greater than 2 feet, since the I-beams themselves will prevent shrinkage immediately around them.

Table for Slab Computation. The necessity of very frequently computing the required thicknesses of slabs, renders very useful a table such as is shown in Table IX, which has been worked out on the basis of 1:3:6 concrete, and computed by solving Equation 13 for various thicknesses d, and for various spans L varying by single feet. It should be noted that the loads as given are *ultimate* loads *per square foot*, and that they therefore include the weight of the slab itself, which must be multiplied by its factor of safety, which is usually considered as 2.

For example, in the above numerical case, we computed that there would be a total load of 700 pounds on a span of 6 feet. In the column headed 6, we find 794 on the same line as the value of 3.0 in the column d. This shows that 3.0 is somewhat excessive for the value of d. We computed its precise value to be 2.82. On the same line, we find under "Spacing of Bars," that ⅜-inch square bars spaced 5½ inches will be sufficient. In the above more precise calculation, we found that the bars could be spaced 6 inches apart, as was to be expected, since the computed ultimate load is considerably less than the nearest value found in the table.

Example 1. What is the ultimate load that will be carried by a 5-inch slab on a span of 10 feet using 1:3:6 concrete?

TABLE IX

Ultimate Load on Slabs of "Average" Concrete (1:3:6) in Pounds per Square Foot Weight of Slab Included

Effective Thickness of Slab d	Area of Steel in 12-In. Width	Spacing of Bars		Span in Feet (*L*)											
		⅜-In. Sq.	½-In. Sq.	4	5	6	7	8	9	10	11	12	13	14	15
2.5	.252	6¾ in.	12 in.	1,241	794	551	405	310	245	198	.....	.....	.....	.....	.....
3.0	.302	5½ "	10 "	1,786	1,143	794	583	446	353	286	226	198	.....	.....	.....
3.5	.353	4¾ "	8½ "	2,432	1,556	1,080	793	608	480	389	322	270	230	198	.....
4.0	.403	4¼ "	7½ "	3,176	2,033	1,411	1,037	794	627	508	420	353	300	259	226
4.5	.454	3¾ "	6¾ "	4,020	2,573	1,786	1,312	1,005	794	643	531	446	380	328	286
5.0	.504	3⅜ "	6 "	4,962	3,176	2,206	1,620	1,241	980	794	656	551	470	405	353
5.5	.554	3 "	5½ "	6,005	3,843	2,669	1,960	1,501	1,186	960	794	667	569	490	427
6.0	.605	.....	5 "	.....	4,573	3,176	2,331	1,787	1,412	1,142	945	793	677	583	508
7.0	.706	.....	4¼ "	.....	.....	4,323	3,176	2,432	1,921	1,556	1,286	1,080	921	794	692
8.0	.806	.....	3¾ "	.....	.....	.....	4,148	3,176	2,509	2,033	1,680	1,410	1,203	1,037	904

Answer. The 5 inches here represent the total thickness, and we shall assume that the effective thickness (d) is 1-inch less. Therefore $d = 4$ inches. On the line opposite $d = 4$ in Table IX, and under the column L = 10, we have 508, which gives the ultimate load per square foot. A 5-inch slab will weigh approximately 60 pounds per square foot, allowing 12 pounds per square foot per inch of thickness. Using a factor of 2, we have 120 pounds, which, subtracting from 508, leaves 388 pounds; dividing this by 4, we have 97 pounds per square foot as the allowable working load. Such a load is heavier than that required for residences or apartment houses. It would do for an office building.

Example 2. The floor of a factory is to be loaded with a live load of 300 pounds per square foot, the slab to be supported on beams spaced 8 feet apart. What must be the thickness of the floor slab?

Answer. With 1,200 pounds per square foot ultimate load for the live load alone, we notice in Table IX, under $L = 8$, that 1,241 is opposite to $d = 5$. This shows that it would require a slab nearly 6 inches thick to support the live load alone. We shall therefore add another half-inch as an estimated allowance for the weight of the slab and, assuming that a 6½-inch slab having a weight of 78 pounds per square foot will do the work, we multiply 300 by 4, and 78 by 2, and have 1,356 pounds per square foot as the ultimate load to be carried. Under $L = 8$, in Table IX, we find that 1,356 comes between 1,241 and 1,501, showing that a slab with an effective thickness d of about 5¼ inches will have this ultimate carrying capacity. The total thickness of the slab should therefore be about 6¼ inches. The table also shows that ½-inch bars spaced about 5¾ inches apart will serve for the reinforcement. We might also provide the reinforcement by ⅜-inch square bars spaced a little over 3 inches apart; but it would probably be better policy to use the half-inch bars, especially since the ⅜-inch bars will cost somewhat more per pound.

Practical Methods of Spacing Slab Bars. It is too much to expect of workmen that bars will be accurately spaced when their distance apart is expressed in fractions of an inch. But it is a comparatively simple matter to require the workmen to space the bars evenly, provided it is accurately computed how many bars should be laid in a given width of slab. For example, in the above case, a panel of the flooring which is, say, 20 feet wide, should have a definite number of bars, 20 feet = 240 inches, and $240 \div 5.75 = 41.7$. We will call this 42, and instruct the workmen to distribute 42 bars equally in the panel 20 feet wide. The workmen can do this without even using a foot-rule, and can adjust them to an even spacing with sufficient accuracy for the purpose.

Table for Computation of Simple Beams. In Table X has been computed for convenience, the ultimate total load on rectangular beams made of average concrete (1:3:6) and with a width of 1 inch. For other widths, multiply by the width of the beam. Since $M_0 = \frac{1}{8} W_0 l$; and since by Equation 13, for this grade of concrete, $M_0 = 397\, b d^2$; and since for a computation of beams 1 inch wide, $b = 1$, we may write $\frac{1}{8} W_0 l = 397\, d^2$. For l we shall substitute $12\, L$. Making this substitution and solving for W_0, we have $W_0 = 265\, d^2 \div L$. Since $b = 1$, A, the area of steel per inch of width of the beam $= .0084\, d$.

Example. What is the ultimate total load on a simple beam having a depth of 16 inches to the reinforcement, 12 inches wide and having a span of 20 feet?

Answer. Looking in Table X, under $L = 20$, and opposite $d = 16$, we find that a beam 1 inch wide will sustain a total load of 3,392 pounds. For a width of 12 inches, the total ultimate load will be $12 \times 3{,}392 = 40{,}704$ pounds. At 144 pounds per cubic foot, the beam will weigh 3,840 pounds. Using a factor of 2 on this, we shall have 7,680 pounds, which, subtracted from 40,704, gives 33,024. Dividing this by 4, we have 8,256 lbs. as the allowable live load on such a beam.

Resistance to the Slipping of the Steel in the Concrete. The previous discussion has considered merely the tension and compression in the upper and lower sides of the beam. A plain, simple beam resting freely on two end supports, has neither tension nor compression in the fibers at the ends of the beam. The horizontal tension and compression, found at or near the center of the beam, entirely disappear by the time the end of the beam is reached. This is done by transferring the tensile stress in the steel at the bottom of the beam, to the compression, fibers in the top of the beam, by means of the intermediate concrete. This is, in fact, the main use of the concrete in the lower part of the beam.

TABLE X

Ultimate Total Load on Rectangular Beams of Average Concrete (1:3:6), One Inch Wide

For other widths, multiply by width of beam. Formula: $W_o = 265\,d^2 \div L$; $A = .0084\,d$. Ultimate compression in concrete 2,000 pounds per sq. in.; ultimate tension in steel 55,000 pounds per sq. in.

Effective Depth of Beam, *d*	Area of Steel per Inch of Width	Span in Feet (*L*)																	Twice Dead Load per Foot of Beam
		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
4	.0336	1,060	848	707	606	530	471	424	385	353	326	303	283	265	249	236	223	212	10
5	.0420	1,656	1,324	1,101	946	828	736	662	602	552	510	473	441	414	390	368	349	331	12
6	.0504	2,385	1,908	1,590	1,363	1,192	1,060	951	867	795	734	681	636	596	561	530	502	477	15
7	.0588	3,246	2,596	2,164	1,855	1,623	1,443	1,298	1,180	1,082	999	927	865	812	761	721	683	649	17
8	.0672	4,240	3,392	2,827	2,423	2,120	1,884	1,696	1,542	1,413	1,305	1,211	1,131	1,060	998	942	893	848	20
9	.0756	5,366	4,292	3,577	3,066	2,683	2,385	2,146	1,951	1,789	1,651	1,533	1,431	1,341	1,263	1,192	1,130	1,073	22
10	.0840	6,625	5,300	4,417	3,786	3,312	2,944	2,650	2,409	2,208	2,038	1,893	1,767	1,656	1,559	1,472	1,395	1,325	24
11	.0924	8,016	6,412	5,344	4,581	4,008	3,563	3,206	2,915	2,672	2,466	2,290	2,137	2,004	1,886	1,781	1,688	1,603	26
12	.1008	9,540	7,632	6,360	5,451	4,770	4,240	3,816	3,469	3,180	2,935	2,726	2,544	2,385	2,245	2,120	2,008	1,908	28
13	.1092	11,196	8,957	7,464	6,398	5,598	4,976	4,478	4,071	3,732	3,445	3,199	2,986	2,799	2,634	2,488	2,357	2,239	30
14	.1176	12,985	10,388	8,657	7,420	6,492	5,771	5,194	4,722	4,328	3,995	3,710	3,463	3,246	3,055	2,886	2,734	2,597	32
15	.1260	14,906	11,924	9,937	8,518	7,453	6,625	5,962	5,420	4,969	4,586	4,259	3,975	3,726	3,508	3,312	3,138	2,981	34
16	.1344	16,960	13,568	11,307	9,691	8,480	7,538	6,784	6,167	5,653	5,218	4,845	4,523	4,240	3,991	3,769	3,571	3,392	36
17	.1428	19,146	15,317	12,761	10,941	9,573	8,509	7,658	6,962	6,382	5,891	5,470	5,106	4,786	4,505	4,255	4,031	3,929	38
18	.1512	21,465	17,172	14,310	12,266	10,732	9,540	8,586	7,805	7,155	6,605	6,133	5,724	5,366	5,051	4,770	4,519	4,293	40
19	.1596	23,916	19,133	15,944	13,666	11,958	10,629	9,566	8,697	7,972	7,359	6,833	6,378	5,979	5,627	5,315	5,035	4,783	42
20	.1680	26,500	21,200	17,667	15,143	13,250	11,778	10,600	9,636	8,833	8,151	7,571	7,067	6,625	6,235	5,889	5,579	5,300	44

For values in the lower left-hand corner of the table, possible failure by diagonal shear must be very carefully tested and provided for.

It is therefore necessary that the bond between the concrete and the steel shall be sufficiently great to withstand the tendency to slip. The required strength of this bond is evidently equal to the difference in the tension in the steel per unit of length. For example, suppose that we are considering a bar 1-inch square in the middle of the length of a beam. Suppose that the bar is under an actual tension of 15,000 pounds per square inch. Since the bar is 1-inch square, the actual total tension is 15,000 pounds. Suppose that, at a point 1 inch beyond, the moment in the beam is so reduced that the tension in the bar is 14,900 pounds instead of 15,000 pounds. This means that the difference of pull (100 pounds) has been taken up by the concrete. The surface of the bar for that length of one inch, is four square inches. This will require an adhesion of 25 pounds per square inch between the steel and the concrete, in order to take up this difference of tension The adhesion between concrete and plain bars is usually considerably greater than this and there is therefore but little question about the bond in the center of the beam. But near the ends of the beam, the change in tension in the bar is far more rapid, and it then becomes questionable whether the bond is sufficient.

Although there is no intention to argue the merits of any form of patented bar, this discussion would not be complete without a statement of the arguments in favor of *deformed* bars, or bars with *a mechanical bond,* instead of plain bars. The deformed bars have a variety of shapes; and since they are not prismatic, it is evident that, apart from adhesion, they cannot be drawn through the concrete without splitting or crushing the concrete immediately around the bars. The choice of form is chiefly a matter of designing a form which will furnish the greatest resistance, and which at the same time is not unduly expensive to manufacture. Of course, the deformed bars are necessarily somewhat more expensive than the plain bars. The main line of argument of those engineers who defend the use of plain bars, may be summed up in the assertion that the plain bars are "good enough," and that, since they are less expensive than deformed bars, the added expense is useless. The arguments in favor of a mechanical bond, and against the use of plain bars, are based on three assertions:

First: It is claimed that tests have apparently verified the assertion that the mere soaking of the concrete in water for several months is sufficient to reduce the adhesion from $\frac{1}{2}$ to $\frac{2}{3}$. If this contention is true, the adhesion of bars in concrete which is likely to be perpetually soaked in water, is unreliable.

Second: Microscopical examination of the surface of steel, and of concrete which has been moulded around the steel, shows that the adhesion depends chiefly on the roughness of the steel, and that the cement actually enters into the microscopical indentations in the surface of the metal. Since a stress in the metal even within the elastic limit necessarily reduces its cross-section somewhat, the so-called adhesion will be more and more reduced as the stress in the metal becomes greater. This view of the case has been verified by recent experiments by Professor Talbot, who used bars made of tool steel in many of his tests. These bars were exceptionally smooth; and concrete beams reinforced with these bars failed generally on account of the slipping of the bars. Special tests to determine the bond resistance, showed that it was far lower than the bond resistance of ordinary plain bars.

Third: There is evidence to show that long-continued vibration, such as is experienced in many kinds of factory buildings, etc., will destroy the adhesion during a period of years. Some failures of buildings and structures which were erected several years ago, and which were long considered perfectly satisfactory, can hardly be explained on any other hypothesis. Owing to the fact that there are comparatively few reinforced concrete structures which have been built for a very long period of years, positive information as to the durability and permanency of adhesion is lacking. It must be conceded, however, that comparative tests of the bond between concrete and steel when the bars are plain and when they are deformed (the tests being made within a few weeks or months after the concrete is made), have comparatively little value as an indication of what that bond will be under some of the adverse circumstances mentioned above, which are perpetually occurring in practice. Non-partisan tests have shown that, even under conditions which are most favorable to the plain bars, the deformed bars have an actual hold in the concrete which is from 50 to 100 per cent greater than that of plain bars. It is unquestionable that age will increase rather than diminish the relative inferiority of plain bars.

Computation of the Bond Required in Bars. From Equation 11 we have the formula that the resisting moment at any point in the beam equals the area of the steel, times the unit tensile stress in the steel, times the distance from the steel to the centroid of compression of the steel, which is the distance $d - x$. We may compute the moment in the beam at two points at a unit distance apart. The area of the steel is the same in each equation, and $d - x$ is substantially the same in each case; and therefore the *difference* of moment, divided by $(d - x)$, will evidently equal the *difference* in the unit stress in the steel, times the area of the steel. To express this in an equation, we may say, denoting the difference in the moment by dM, and the difference in the unit stress in the steel by ds:

$$\frac{dM}{(d - x)} = A \times ds.$$

But $A \times ds$ is evidently equal to the actual difference in tension in the steel, measured in pounds. It is the amount of tension which must be transferred to the concrete in that unit length of the beam. But the computations of the difference of moments at two sections that are only a unit distance apart, is a comparatively tedious operation, which, fortunately, is unnecessary. Theoretical mechanics teaches us that the difference in the moment at two consecutive sections of the beam is measured by the *total vertical shear* in the beam at that point. The shear is very easily and readily computable; and therefore the required amount of tension to be transferred from the steel to the concrete can readily be computed. A numerical illustration may be given as follows: Suppose that we have a beam which, with its load, weighs 20,000 pounds, on a span of 20 feet. Using ultimate values, for which we multiply the loading by 4, we have an ultimate loading of 80,000 pounds. Therefore,

$$M_o = \frac{W_o\, l}{8} = \frac{80{,}000 \times 240}{8} = 2{,}400{,}000.$$

Using the constants previously chosen for 1:3:6 concrete, and therefore utilizing Equation 13, we have this moment equal to 397 bd^2. Therefore $bd^2 = 6{,}045$.

If we assume $b = 15$ inches; $d = 20.1$ inches; then $d - x = .86d = 17.3$ inches. The area of steel equals

$$A = .0084\, b\, d = 2.53 \text{ square inches.}$$

We know from the laws of mechanics, that the moment diagram for a beam which is uniformly loaded is a parabola, and that the ordinate to this curve at a point one inch from the abutment will, in the above case, equal $(\frac{119}{120})^2$ of the ordinate at the abutment. This ordinate is measured by the maximum moment at the center, multiplied by the factor $(\frac{119}{120})^2 = \frac{14,161}{14,400} = .9834$; therefore the actual moment at a point one inch from the abutment $= (1.00 - .9834) = .0166$ of the moment at the center. But $.0166 \times 2,400,000 = 39,840$.

But our ultimate loading being 80,000 pounds, we know that the shear at a point in the middle of this one-inch length equals the shear at the abutment, minus the load on this first $\frac{1}{2}$ inch, which is $\frac{1}{240}$ of 40,000 (or 167) pounds. The shear at this point is therefore $40,000 - 167$ (or 39,833) pounds. This agrees with the above value 39,840 as closely as the decimals used in our calculations will permit.

The value of $d - x$ is somewhat larger when the moment is very small than when it is at its ultimate value. But the difference is comparatively small, is on the safe side, and it need not make any material difference in our calculations. Therefore, dividing 39,840 by 17.3, we have 2,303 pounds as the difference in tension in the steel in the last inch at the abutment. Of course this does not literally mean the last inch in the length of the beam, since, if the net span were 20 feet, the actual length of the beam would be considerably greater. The area of the steel as computed above is 2.53 square inches. Assuming that this is furnished by five $\frac{3}{4}$-inch square bars, the surfaces of these five bars per inch of length equals 15 square inches. Dividing 2,303 by 15, we have 153 pounds per square inch as the required adhesion between the steel and the concrete. While this is not greater than the adhesion usually found between concrete and steel, it is somewhat risky to depend on this; and therefore the bars are usually bent so that they run diagonally upward, and thus furnish a very great increase in the strength of the beam, which prevents the beam from failing at the ends. Tests have shown that beams which are reinforced by bars only running through the lower part of the beam without being turned up, or without using any stirrups, will usually fail at the ends, long before the transverse moment, which they possess at their center, has been fully developed.

Distribution of Vertical Shears. Beams which are tested to destruction frequently fail at the ends of the beams, long before the transverse strength at the center has been fully developed. Even if the bond between the steel and the concrete is amply strong for the requirements, the beam may fail on account of the shearing or diagonal stresses in the concrete between the steel and the neutral axis. The student must accept without proof some of the following statements regarding the distribution of the shear.

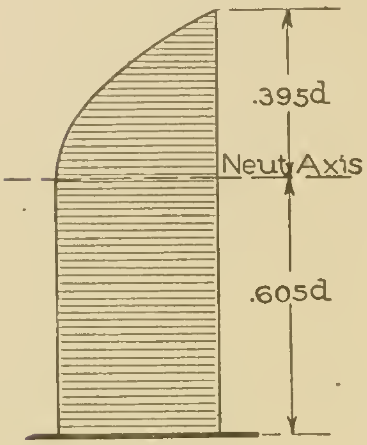


Fig. 43.

The intensity of the shear at various points in the height of the beam, may be represented by the diagram in Fig. 43. If we ignore the tension in the concrete due to transverse bending, the shear will be uniform between the steel and the neutral axis. Above the neutral axis, the shear will diminish toward the top of the beam, the curve being parabolic.

If the distribution of the shear were uniform throughout the section, we might say that the shear per square inch would equal $V \div bd$. It may be proved that v, the intensity of the vertical shear per square inch, is

$$v = \frac{V}{b\,(d - x)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

In the above case, the ultimate total shear V in the last inch at the end of the beam, is 39,840 pounds. Then,

$$v = \frac{39{,}840}{15 \times 17.3} = 153.5 \text{ pounds per square inch.}$$

The agreement of this numerical value of the unit intensity of the vertical shear with the required bond between the concrete and the steel, is due to the accidental agreement of the width of the beam (15 inches) with the superficial area of the bars per inch of length of the beam (15 square inches). If other bars of the same *cross-sectional* area, but with greater or less superficial surface, had been selected for the reinforcement, even this accidental agreement would not have been found.

The actual strength of concrete in shear is usually far greater than this. The failure of beams, which fail at the ends when loaded with loads far within their capacity for transverse strength, is generally due to the *secondary stresses*. The computation of these stresses is a complicated problem in Mechanics; but it may be proved that if we ignore the tension in the concrete due to bending stresses, the diagonal tension per unit of area equals the vertical shear per unit of area (v). But concrete which may stand a shearing stress of 1,000 pounds per square inch will probably fail under a direct tension of 200 pounds per square inch. The diagonal stress has the nature of a direct tension. In the above case the beam probably would not fail by this method of failure, since concrete can usually stand a tension up to 200 pounds per square inch; but such beams, when they are not diagonally reinforced, frequently fail in that way before their ultimate loads are reached.

Methods of Guarding against Failure by Shear or Diagonal Tension. The failure of a beam by actual shear is almost unknown. The failures usually ascribed to shear are generally caused by diagonal tension. A solution of the very simple equation (15) will indicate the intensity of the vertical shear.

The relation of crushing strength to shearing strength is expressed by the equation:

$$\text{Unit shearing strength } z = \frac{c'}{2 \tan \theta'}$$

in which z is the unit shearing strength, and θ is the angle of rupture under direct compression. This angle is usually considered to be 60°; for such a value the shearing strength would equal $c' \div 3.464$. When $\theta = 45°$, the shearing strength would equal *one-half* of the crushing strength, and this agrees very closely with the results of tests made by Professor Spofford. But the shearing strength is considered to be a far less reliable quantity than the crushing strength; and therefore dependence is not placed on shear, even for *ultimate* loading, to a greater value than about one-half of the above value; or,

$$\text{Unit shearing strength } z = c' \div 6.928.$$

Usually the unit intensity of the vertical shear (even for ultimate loads) is less than this. But this ignores the assistance furnished by the bars. Actual failure would require that the bars must crush the concrete under them. When, as is usual, there are bars passing obliquely through the section, a considerable portion of the shear is carried by direct tension in the bars.

It seems impracticable to develop a rational formula for the amount of assistance furnished by these diagonal bars, unless we make assumptions which are doubtful and which therefore vitiate the reliability of the whole calculation. Therefore the "rules" which have been suggested for a prevention of this form of failure are wholly empirical. Mr. E. L. Ransome uses a rule for spacing vertical "stirrups," made of wires or $\frac{1}{4}$-inch rods, as follows:

The first stirrup is placed at a distance from the end of the beam equal to one-fourth the depth of the beam; the second is at a distance of one-half the depth beyond the first stirrup; the third, three-fourths of the depth beyond the second; and the fourth, a distance equal to the depth of the beam beyond the third. This empirical rule agrees with the theory, in the respect that the stirrups are closer at the ends of the beam, where the shear is greatest. The four stirrups extend for a distance from the end equal to $2\frac{1}{2}$ times the depth of the beam. Usually this is a sufficient distance; but some "systems" use stirrups throughout the length of the beam. On very short beams, the shear changes so rapidly that at $2\frac{1}{2}$ times the depth from the end of the beam the shear is not generally so great as to produce dangerous stresses. With a very long beam, the change in the shear is correspondingly more gradual; and it is possible that stirrups or some other device must be used for a greater actual distance from the end, although for a less proportional distance.

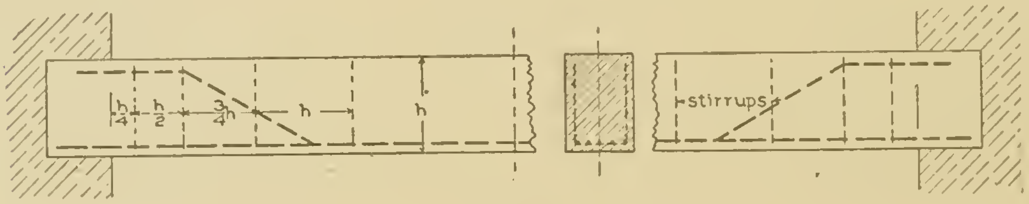


Fig. 44.

When the diagonal reinforcement is accomplished by bending up the bars at an angle of about 45°, the bending should be done so that there is at all sections a sufficient area of steel in the lower part of the bar to withstand the transverse moment at that section. As fast as the bars can be spared from the bottom of the beam, they may be turned up diagonally so that there are at every section of the beam one or more bars which would be cut diagonally by such a section. On this account it is far better to use a larger number of bars, than a smaller number of the same area. For example, if it were required that there shall be 2.25 square inches of steel for the section at the middle of the beam, it would be far better to use nine $\frac{1}{2}$-inch bars than four $\frac{3}{4}$-inch bars. In either case, the steel has the same area and the same weight. The nine $\frac{1}{2}$-inch bars give a much better distribution of the metal. The superficial area of the nine $\frac{1}{2}$-inch bars is 18 square inches per linear inch of the beam, while the area of the four $\frac{3}{4}$-inch bars is only 12 square inches per inch of length. But an even greater advantage is furnished by the fact that we have nine bars instead of four, which may be bent upward (and bent more easily than the $\frac{3}{4}$-inch bars) as fast as they can be spared from the bottom of the beam. In this way the shear near the end of the beam may be much more effectually and easily provided for.

Since the shear is greatest at the ends of the beam, more bars should be reserved for turning up near the ends. For example, in the above case of the nine bars, one or two bars might be turned up at about the quarter-points of the beam. One or two more might be turned up at a distance equal to, or a little less than, the depth of the beam from the quarter-points toward the abutments. Others would be turned up at intermediate points; at the abutments there should be at least two, or perhaps three, diagonal bars, to take up the maximum shear near the abutments. This is illustrated, although without definite calculations, in Fig. 45.

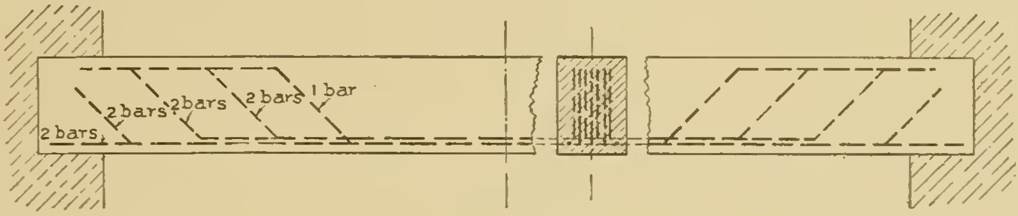


Fig 45.

Detailed Design of a Plain Beam. This will be illustrated by a numerical example. A beam having a span of 18 feet supports one side of a 6-inch slab 8 feet wide which carries a live load of 200 pounds per square foot. In addition, a special piece of machinery, weighing 2,400 pounds, is located on the slab so near the middle of the beam that we shall consider it to be a concentrated load at the center of the beam. The floor area carried by the beam is 18 feet by 4 feet = 72 square feet. Adding 3 inches to the 6 inches thickness of the slab as an allowance for the weight of the beam, we have $9 \times 12 = 108$ pounds per square foot for the dead weight of the floor. With a factor of 2 for dead load, this equals 216. Using a factor of 4 on the live load (200), we have 800 pounds per square foot. Then the ultimate load on the beam, due to these sources, is $(216 + 800)\ 72 = 73{,}152$ pounds. So far as its effect on moment is concerned, the concentrated load of 2,400 pounds at the center would have the same effect as 4,800 pounds uniformly distributed. As it is a piece of vibrating machinery, we shall use a factor of *six* (6), and thus have an ultimate effect of $6 \times 4{,}800 = 28{,}800$ pounds. Adding this to 73,152, we have 101,952 pounds as the equivalent, ultimate, uniformly distributed load. Then

$$M_o = \tfrac{1}{8}\,W_o\,l = \tfrac{1}{8} \times 101{,}952 \times 216 = 2{,}752{,}704.$$

In order to reduce as much as possible the size and weight of this beam, we shall use 1:2:4 concrete, and therefore apply Equation **14**:

$$2{,}752{,}704 = 565\,b\,d^2;$$
$$bd^2 = 4{,}872.$$

If $b =$ 16 inches; $d^2 = 304.5$, and $d = 17.5$ inches.

A still better combination would be a deeper and narrower beam with $b = 12$ inches, and $d = 20.15$ inches. With this combination, the required area of the steel will equal

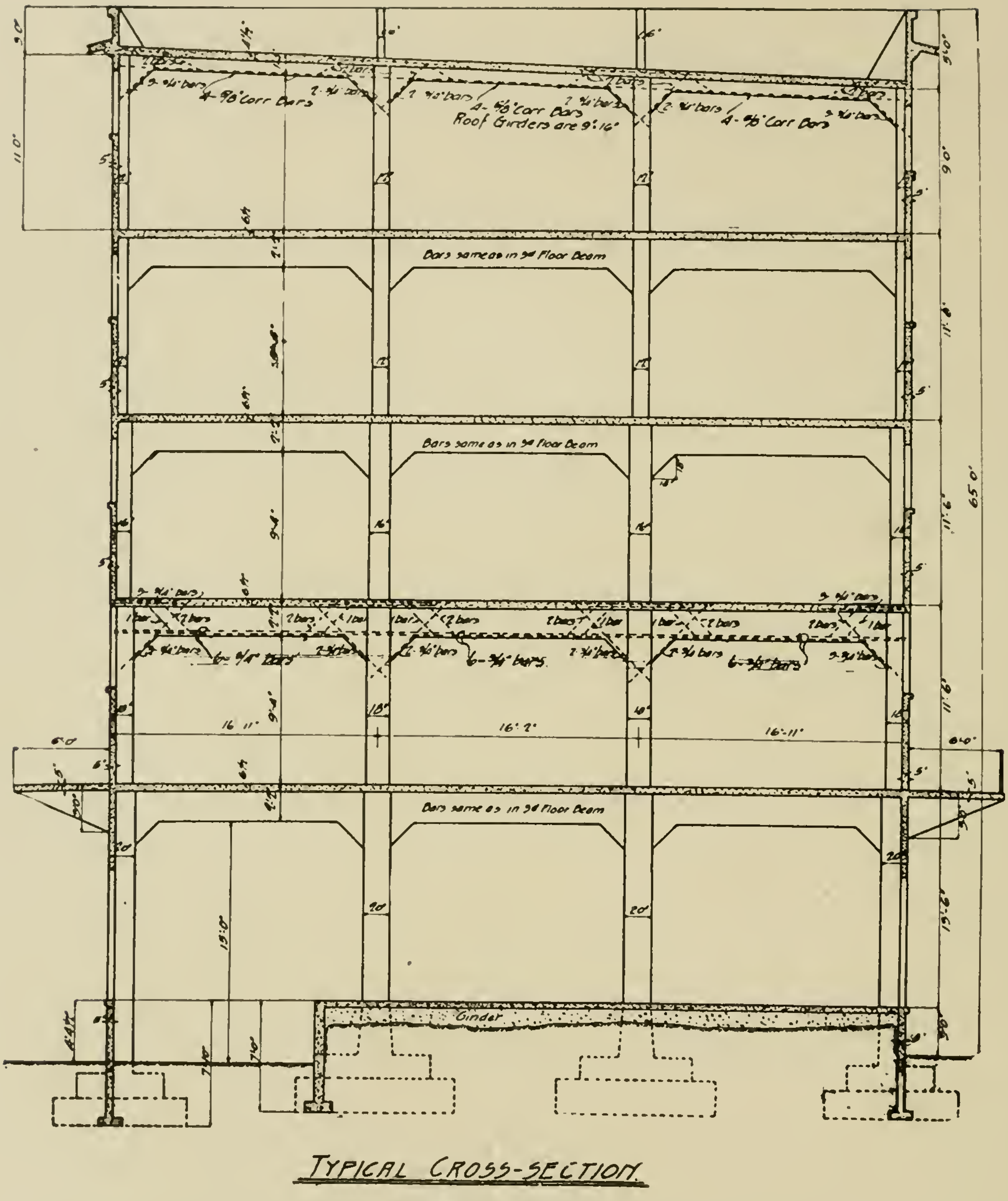
$$A = .0121\,bd = .0121 \times 12 \times 20.15 = 2.93 \text{ square inches.}$$

This can be supplied by eight bars $\frac{5}{8}$ inch square.

The total ultimate load as determined above, is 101,952 pounds. One-half of this gives the maximum shear at the ends, or 50,976 pounds. Applying Equation **15**, we have, since $d - x = .85\,d = 17$ inches

$$v = \frac{V}{b\,(d-x)} = \frac{50{,}796}{12 \times 17} = 249 \text{ pounds per square inch.}$$

As already discussed in previous cases, the ends of the beam must be reinforced against diagonal tension, since the above value of v is too great, even as an ultimate value, for such stress. Therefore the ends of the beam must be reinforced by turning the bars up, or by the use of stirrups. The beam must therefore be reinforced about as



SECTION THROUGH A FIVE-STORY WAREHOUSE BUILT OF REINFORCED CONCRETE.

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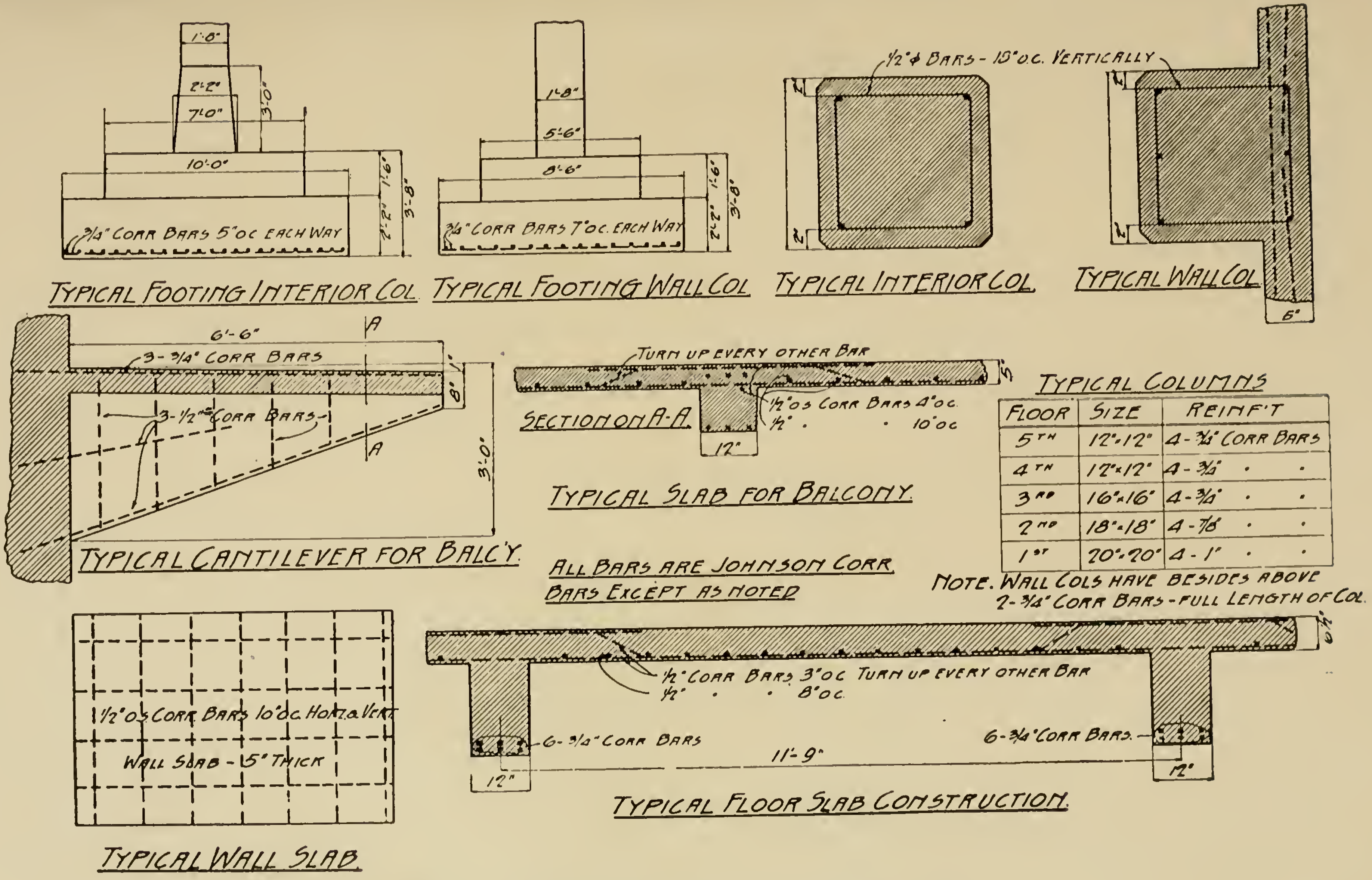

1'-0"
2'-2"
7'-0"
3'-0"
10'-0"
1'-6"
2'-2"
3'-8"
3/4" CORR BARS 5" O.C. EACH WAY
TYPICAL FOOTING INTERIOR COL.
1'-8"
5'-6"
8'-6"
1'-6"
2'-2"
3'-8"
3/4" CORR BARS 7" O.C. EACH WAY
TYPICAL FOOTING WALL COL
1/2" ϕ BARS - 18" O.C. VERTICALLY
2"
2"
TYPICAL INTERIOR COL.
TYPICAL WALL COL.
6"
6'-6"
A
3-3/4" CORR BARS
3-1/2" CORR BARS
A
8"
3'-0"
TYPICAL CANTILEVER FOR BALC'Y.
TURN UP EVERY OTHER BAR
5"
1/2" O.S CORR BARS 4" O.C.
1/2" " " 10" O.C.
SECTION ON A-A
12"
TYPICAL SLAB FOR BALCONY
ALL BARS ARE JOHNSON CORR BARS EXCEPT AS NOTED
TYPICAL COLUMNS
NOTE. WALL COLS HAVE BESIDES ABOVE 2-3/4" CORR BARS - FULL LENGTH OF COL.
1/2" O.S CORR BARS 10" O.C. HOR. & VERT.
WALL SLAB - 5" THICK
TYPICAL WALL SLAB.
1/2" CORR BARS 3" O.C. TURN UP EVERY OTHER BAR
1/2" " " 8" O.C.
6-3/4" CORR BARS
11'-9"
6-3/4" CORR BARS.
12"
12"
4"
TYPICAL FLOOR SLAB CONSTRUCTION.

FLOOR	SIZE	REINF'T
5TH	12"×12"	4-3/4" CORR BARS
4TH	12"×12"	4-3/4" " "
3RD	16"×16"	4-3/4" " "
2ND	18"×18"	4-7/8" " "
1ST	20"×20"	4-1" " "

DETAILS OF WAREHOUSE BUILT OF REINFORCED CONCRETE.

Reproduced by Courtesy of Expanded Metal & Corrugated Bar Company.

shown in Fig. 46. Although the concentrated center load in this case is comparatively too small to require any change in the design, it should not be forgotten that a concentrated load *may* cause the shear to change so rapidly that it might require special provision for it in the center of the beam, where there is ordinarily no reinforcement which will assist shearing stresses.

Effect of Quality of Steel. There is one very radical difference between the behavior of a concrete-steel structure and that of a structure composed entirely of steel, such as a truss bridge. A truss bridge may be overloaded with a load which momentarily passes the elastic limit, and yet the bridge will not necessarily fail nor cause the truss to be so injured that it is useless and must be immediately replaced. The truss might sag a little, but no immediate failure is imminent. On this account, the factor of safety on truss bridges is usually computed on the basis of the ultimate strength.

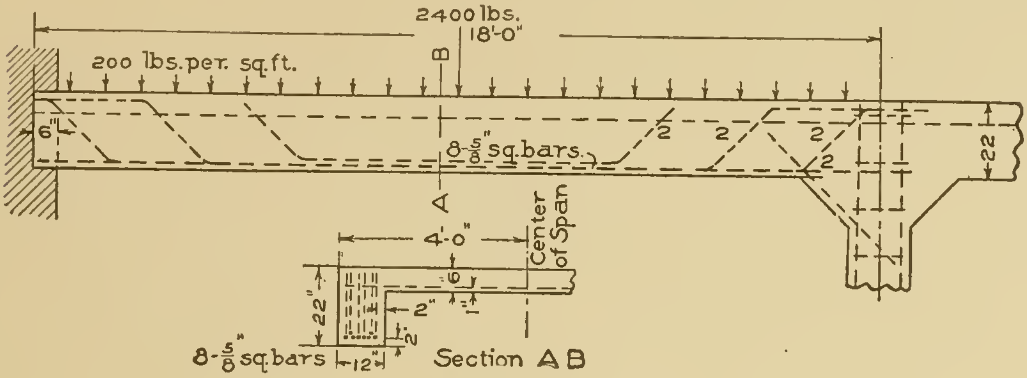


Fig. 46. Reinforced Beam.

A concrete-steel structure acts very differently. As has already been explained, the intimate union of the concrete and the steel at *all* points along the length of the bar (and not merely at the ends), is an absolute essential for stability. If the elastic limit of the steel has been exceeded owing to an overload, then the union between the concrete and the steel has unquestionably been destroyed, provided that union depends on mere adhesion. Even if that union is assisted by a mechanical bond, the distortion of the steel has broken that bond to some extent, although it will still require a very considerable force to pull the bar through the concrete. It is therefore necessary that the elastic limit of the steel should be considered the virtual ultimate so far as the strength of the steel is concerned. It is accordingly considered advisable, as already explained, to multiply all working loads by the desired factor of safety (usually taken as 4), and then to proportion the steel and concrete so that such an ultimate load will produce crushing in the upper fiber of the concrete, and at the same time will stress the steel to its elastic limit. On this basis, economy in the use of steel requires that the elastic limit should be made as high as possible.

The manufacture of steel of very high elastic limit requires the use of a comparatively large proportion of carbon, which may make the steel objectionably brittle. The steel for this purpose must therefore avoid the two extremes—on the one hand, of being brittle; and on the other, of being so soft that its elastic limit is very low.

Several years ago, bridge engineers thought that a great economy in bridge construction was possible by using *very* high carbon steel, which has not only a high elastic limit but also a correspondingly high ultimate tensile strength. But the construction of such bridges requires that the material shall be punched, forged, and otherwise handled in a way that will very severely test its strength and perhaps cause failure on account of its brittleness. The stresses in a concrete-steel structure are very different. The steel is never punched; the individual bars are never subjected to transverse bending *after* being placed in the concrete. The direct shearing stresses are insignificant. The main use, and almost the only use, of the steel, is to withstand a direct tension; and on this account a considerably harder steel may be used than is usually considered advisable for steel trusses.

If the structure is to be subject to excessive impact, a somewhat softer steel will be advisable; but even in such a case, it should be remembered that the mere weight of the structure will make the effect of the shock far less than it would be on a skeleton structure of plain steel. The steel ordinarily used in bridge work, generally has an elastic limit of from 30,000 to 35,000. If we use even 33,000 pounds as the value for s on the basis of ultimate loading, we shall find that the required percentage of steel is very high. On the other hand, if we use a grade of steel in which the carbon is somewhat higher, having an ultimate strength of about 90,000 to 100,000 pounds per square inch, and an elastic limit of 55,000 pounds per square inch, the required percentage of steel is much lower.

A study of Equation 10 will show that for any one kind of concrete the percentage of steel increases even *faster* than the value of s diminishes—which means, for example, that if s is diminished 50 per cent, p is *more* than doubled. Notwithstanding this incontrovertible fact, some engineers insist on using a low percentage of soft steel, apparently ignoring the fact that the elastic limit of the steel will be reached, and the structure will fail, long before the full strength of the concrete has been developed. There is, of course, no harm in using soft steel, provided a sufficient percentage of steel is used; but it should be remembered that formulæ developed on the basis of high elastic limit (or a high value of s) *must not* be used for soft steel. It will not even be correct to say that, because the ultimate *breaking* strength of soft steel is 60,000 pounds, we may employ formulæ with $s = 55{,}000$. Such formulæ are derived on the basis that the concrete reaches its ultimate compression (say 2,000 pounds) when the stress in the steel is 55,000. But since the soft steel cannot exceed 30,000 pounds without virtual failure, on account of the rupture of the bond between the steel and the concrete, the stress in the concrete will *never* reach 2,000 pounds, nor can it approach relatively as near 2,000 pounds as the steel approaches to 30,000 pounds.

All general equations previous to Equation 13 are perfectly general, except that in some cases q is limited to the value $\frac{2}{3}$. The later equations have, for simplicity, been worked on the uniform basis of steel having an elastic limit, which is its virtual ultimate, of 55,000 pounds, and a modulus of elasticity of 29,000,000. The subsequent tables have also further limited the concrete to that with an ultimate compression (c') of 2,000 pounds, and an initial modulus of elasticity (E_c) of 2,400,000. Other equations, similar to 13 and 14—and other tables, similar to IX to XIV—may be similarly computed for other ultimate tensions in steel and other grades of concrete; but the engineer should be scrupulously careful about using any equations or tables *except for the grades of steel and concrete for which they have been computed.* When other grades of steel and concrete are to be used, the equations must be suitably modified. This can readily be done by deriving equations, similar to Equations 13, 14, and the later equations, from the general equations 1 to 12.

Slabs on I-Beams. There are still many engineers who will not adopt reinforced concrete for the skeleton structure of buildings, but who construct the frames of their buildings of steel, using steel I-beams for floor girders and beams, and then connect the beams with concrete floor slabs. These are usually computed on the basis of transverse beams which are free at the ends, instead of considering them as "continuous beams," which will add about 50 per cent to their strength. Since it would be necessary to move the reinforcing steel from the lower part to the upper part of the slab when passing over the floor beams, in order to develop the additional strength which is theoretically possible with continuous beams, and since this is not usually done, it is by far the safest practice to consider all floor slabs as being "free-ended." The additional strength which they undoubtedly have to some extent because they are continuous over the beams, merely adds indefinitely to the factor of safety. Usually the requirement that the I-beams shall be "fireproofed," by surrounding the beam itself with a layer of concrete such that the outer surface is at least 2 inches from the nearest point of the steel beam, results in having a shoulder of concrete under the end of each slab, which quite materially adds to its structural strength. But usually no allowance is made; nor is there any reduction in the thickness of the slab on account of this added strength. In this case also, the factor of safety is again indefinitely increased. The fireproofing around the beam must usually be kept in place by wrapping a small sheet of expanded metal or wire lath around the lower part of the beam before the concrete is placed.

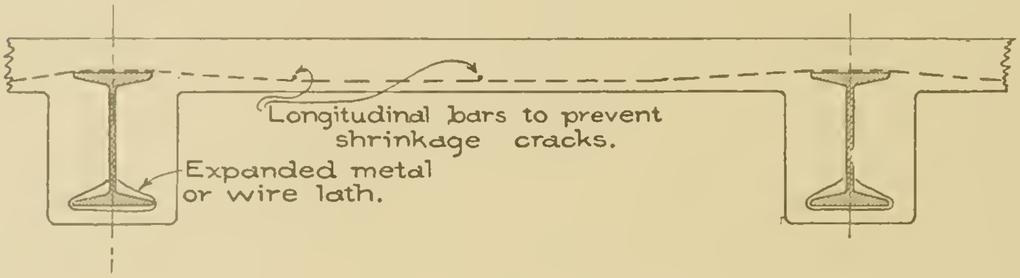

Longitudinal bars to prevent shrinkage cracks.
Expanded metal or wire lath.

Fig. 47.

Slabs Reinforced in Both Directions. When the floor beams of a floor are spaced nearly equally in both directions, so as to form, between the beams, panels which are nearly square, a material saving can be made in the thickness of the slab by reinforcing it with bars running in both directions. The theoretical computation of the strength of such slabs is exceedingly complicated. It is usually considered that such slabs have twice the strength of a slab supported only on two sides and reinforced with bars in but one direction. The usual method of computing such slabs is to compute the slab thickness, and the spacing and size of the reinforcing steel for a slab which is to carry *one-half* of the actual load. Strictly speaking, the slab should be thicker by the thickness of one set of reinforcing bars.

Reinforcement against Temperature Cracks. The modulus of elasticity of ordinary concrete is approximately 2,400,000 pounds per square inch, while its ultimate tensional strength is about 200 pounds per square inch. Therefore a pull of about $\frac{1}{12,000}$ of the length would nearly, if not quite, rupture the concrete. The coefficient of expansion of concrete has been found to be almost identical with that of steel, or .0000065 for each degree Fahrenheit. Therefore, if a block of concrete were held at the ends with absolute rigidity, while its temperature were lowered about 12 degrees, the stress developed in the concrete would be very nearly, if not quite, at the rupture point. Fortunately the ends will not usually be held with such rigidity; but nevertheless it does generally happen that, unless the entire mass of concrete is permitted to expand and contract freely so that the temperature stresses are small, the stresses will usually localize themselves at the weak point of the cross-section, wherever it may be, and will there develop a crack, provided the concrete is not reinforced with steel. If, however, steel is well distributed throughout the cross-section of the concrete, it will prevent the concentration of the stresses at local points, and will distribute it uniformly throughout the mass.

Reinforced concrete structures are usually provided with bars running in all directions, so that temperature cracks are prevented by the presence of such bars, and it is generally unnecessary to make any special provision against such cracks. The most common exception to this statement occurs in floor slabs, which structurally require bars in only one direction. It is found that cracks parallel with the bars which reinforce the slab will be prevented if a few bars are laid perpendicularly to the direction of the main reinforcing bars. Usually $\frac{1}{2}$-inch or $\frac{3}{8}$-inch bars, spaced about 2 feet apart, will be sufficient to prevent such cracks.

Retaining walls, the balustrades of bridges, and other similar structures, which may not need any bars for purely structural reasons, should be provided with such bars in order to prevent temperature cracks. A theoretical determination of the amount of such reinforcing steel is practically impossible since it depends on assumptions which are themselves very doubtful. It is usually conceded that if there is placed in the concrete an amount of steel whose cross-sectional area equals about $\frac{1}{3}$ of 1 per cent of the area of the concrete, the structure will be proof against such cracks. Fortunately, this amount of steel is so small that any great refinement in its determination is of little importance. Also, since such bars have their value in tying the structure together and thus adding somewhat to its strength and ability to resist disintegration owing to vibrations, the bars are usually worth what they cost.

TANKS

Design. The extreme durability of reinforced concrete tanks, and their immunity from deterioration by rust, which so quickly destroys steel tanks, have resulted in the construction of a large and increasing number of tanks in reinforced concrete. Such tanks must be designed to withstand the bursting pressure of the water. If they are very high compared with their diameter, it is even possible that failure might result from excessive wind pressure.

The method of designing one of these tanks may best be considered from an example. Suppose that it is required to design a reinforced concrete tank with a capacity of 50,000 gallons, which shall have an inside diameter of 18 feet. At 7.48 gallons per cubic foot, a capacity of 50,000 gallons will require 6,684 cubic feet. If the inside diameter of the tank is to be 18 feet, then the 18-foot circle will contain an area of 254.5 square feet. The depth of the water in the tank will therefore be 26.26 feet. The lowest foot of the tank will therefore be subjected to a bursting pressure due to 25.76 vertical feet of water. Since the water pressure per square foot increases $62\frac{1}{2}$ pounds for each foot of depth, we shall have a total pressure of 1,610 pounds per square foot on the lowest foot of the tank. Since the diameter is 18 feet, the bursting pressure it must resist on *each* side is one-half of $18 \times 1{,}610 = \frac{1}{2} \times 28{,}980 = 14{,}490$ pounds. If we allow a working stress of 15,000 pounds per square inch, this will require .966 square inch of metal in the lower foot. Since the bursting pressure is strictly proportional to the depth of the water, we need only divide this number proportionally to the depth to obtain the bursting pressure at other depths. For example, the ring one foot high, at one-half the depth of the tank, should have .483 square inch of metal; and that at one-third of the depth, should have .322 square inch of metal. The actual bars required for the lowest foot may be figured as follows: .966 square inch per foot equals .0805 square inch per inch; $\frac{3}{4}$-inch square bars, having an area .5625 square inch, will furnish the required strength when spaced 7 inches apart. At one-half the height, the required metal per linear inch of height is half of the above, or .040. This *could* be provided by using $\frac{3}{4}$-inch bars spaced 14 inches apart; but this is not so good a distribution of metal as to use $\frac{5}{8}$-inch square bars having an area of .39 square inch, and to space the bars nearly 10 inches apart. It would give a still better distribution of metal, to use $\frac{1}{2}$-inch bars spaced 6 inches apart at this point, although the $\frac{1}{2}$-inch bars are a little more expensive per pound, and, if they are spaced very closely, will add slightly to the cost of placing the steel. The size and spacing of bars for other points in the height can be similarly determined.

A circle 18 feet in diameter has a circumference of somewhat over 56 feet. Assuming as a preliminary figure that the tank is to be 10 inches thick at the bottom, the mean diameter of the base ring would be 18.83 feet, which would give a circumference of over 59 feet. Allowing a lap of 3 feet on the bars, this would require that the bars should be about 62 feet long. Although it is possible to have bars rolled of this length, they are very difficult to handle, and require to be transported on the railroads on *two* flat cars. It is therefore preferable to use bars of slightly more than half this length, and to make two joints in each band.

The bands which are used for ordinary wooden tanks are usually fastened at the ends by turn-buckles. Some such method is necessary for the bands of concrete tanks, provided the bands are made of plain bars. Deformed bars have a great advantage in such work, owing to the fact that, if the bars are over-lapped from 18 inches to 3 feet, according to their size, and are then wired together, it will require a greater force than the strength of the bar to pull the joints apart after they are once thoroughly incased in the concrete and the concrete has hardened.

Test for Overturning. Since the computed depth of the water is over 26 feet, we must calculate that the tank will be, say, 28 feet high. Its outer diameter will be approximately 20 feet. The total area exposed to the surface of the wind, will be 560 square feet. We may assume that the wind has an average pressure of 50 pounds per square foot; but owing to the circular form of the tank, we shall assume that its effective pressure is only one-half of this; and therefore we may figure that the total overturning pressure of the wind equals 560 × 25 = 14,000 pounds. If this is considered to be applied at a point 14 feet above the ground, we have an overturning moment of 196,000 foot-pounds, or 2,352,000 inch-pounds. Using a factor of 4 on this, we may consider this as an ultimate moment of 9,408,000 inch-pounds.

Although it is not strictly accurate to consider the moment of inertia of this circular section of the tank as it would be done if it were a strictly homogeneous material, since the neutral axis, instead of being at the center of the section, will be nearer to the compression side of the section, our simplest method of making such a calculation is to assume that the simple theory applies, and then to use a generous factor of safety. The effect of shifting the neutral axis from the center toward the compression side, will be to increase the unit compression on the concrete, and reduce the unit tension in the steel; but, as will be seen, it is generally necessary to make the concrete so thick that its unit compressive stress is at a very safe figure, while the reduction of the unit tension in the steel is merely on the side of safety.

Applying the usual theory, we have, for the moment of inertia of a ring section, .049 $(d_1^4 - d^4)$. Let us assume as a preliminary figure that the wall of the tank is 10 inches thick at the bottom. Its outside diameter is therefore 18 feet + twice 10 inches, or 236 inches. The moment of inertia $I = .049\ (236^4 - 216^4) = 45{,}337{,}842$ biquadratic inches. Calling c the unit compression, we have, as the ultimate moment due to wind pressure:

$$M = \frac{c'\ I}{\frac{1}{2}\ d'} = \frac{c' \times 45{,}337{,}842}{\frac{1}{2}\ d_1} = 9{,}408{,}000 \text{ inch-pounds,}$$

in which $\frac{1}{2}\ d_1 = 118$ inches.

Solving the above equation for c, we have c equals a fraction less than 25 pounds per square inch. This pressure is so utterly insignificant, that, even if we double or treble it to allow for the shifting of the neutral axis from the center, and also double or treble the allowance made for wind pressure, although the pressure chosen is usually considered ample, we shall still find that there is practically no danger that the tank will fail owing to a crushing of the concrete due to wind pressure.

The above method of computation has its value in estimating the amount of steel required for vertical reinforcement. On the basis of 25 pounds per square inch, a sector with an average width of 1 inch and a diametral thickness of 10 inches would sustain a compression of about 250 pounds. Since we have been figuring ultimate stresses, we shall figure an ultimate tension of, say, 55,000 pounds per square inch in the steel. This tension would therefore require $\frac{250}{55,000} =$ .0045 square inch of metal per inch of width. Even if $\frac{1}{4}$-inch bars were used for the vertical reinforcement, they would need to be spaced only about 14 inches apart. This, however, is on the basis that the neutral axis is at the center of the section, which is known to be inaccurate.

A theoretical demonstration of the position of the neutral axis for such a section, is so exceedingly complicated that it will not be considered here. The theoretical amount of steel required is always less than that computed by the above approximate method, but the necessity for preventing cracks, which would cause leakage, would demand more vertical reinforcement than would be required by wind pressure alone.

Practical Details of the Above Design. It was assumed as an approximate figure, that the thickness of the concrete side wall at the base of the tank should be 10 inches. The calculations have shown that, so far as wind pressure is concerned, such a thickness is very much greater than is required for this purpose; but it will not do to reduce the thickness in accordance with the apparent requirements for wind pressure. Although the thickness at the bottom might be reduced below 10 inches, it probably would not be wise to do so. It may, however, be tapered slightly towards the top, so that at the top the thickness will not be greater than 6 inches, or perhaps even 5 inches. The vertical bars in the lower part of the side wall must be bent so as to run into the base slab of the tank. This will bind the side wall to the bottom. The necessity for reinforcement in the bottom of the tank depends very largely upon the nature of the foundation, and also to some extent on the necessity for providing against temperature cracks, as has been discussed in a previous section. Even if the tank is placed on a firm and absolutely unyielding foundation, some reinforcement should be used in the bottom, in order to prevent cracks which might produce leakage. These bars should run from a point near the center, and be bent upward at least 2 or 3 feet into the vertical wall. Sometimes a gridiron of bars running in both directions is used for this purpose. This method is really preferable to the radial method. The methods of making tanks water-tight have already been discussed.

RETAINING WALLS

Essential Principles. The economy of a retaining wall of reinforced concrete lies in the fact that by adopting a skeleton form of construction and utilizing the tensional and transverse strength which may be obtained from reinforced concrete, a wall may be built, of which the volume of concrete is, in some cases, not more than one-third the volume of a retaining wall of plain concrete which would answer the same purpose. Although the cost of reinforced concrete per cubic foot will be somewhat greater than that of plain concrete, it sometimes happens that such walls can be constructed for one-half the cost of plain concrete walls. The general outline of a reinforced concrete retaining wall is similar to the letter L, the base of which is a base-plate made as wide as (and generally a little wider than) the width usually considered necessary for a plain concrete wall. As a general rule, the width of the base should be about one-half the height. The face of the wall is made of a comparatively thin plate whose thickness is governed by certain principles, as explained later. At intervals of 10 feet, more or less, the base-plate and the face are connected by *buttresses*. These buttresses are very strongly fastened by tie-bars to both the base-plate and the face-plate. The stress in the buttresses is almost exclusively tension. The pressure of the earth tends to force the face-plate outward; and therefore the face-plate must be designed on the basis of a vertical slab subjected to transverse stresses which are maximum at the bottom and which reduce to zero at the top.

If the wall is "surcharged" (which means that the earth at the top of the wall is not level, but runs back at a slope), then the face-plate will have transverse stresses even at the top. The base-plate is held down by the pressure of the superimposed earth. The buttresses must transmit the bursting pressure on the face of the wall backward and downward to the base-plate. The base-plate must therefore be designed by the same method as a horizontal slab carrying a load equal and opposite to the upward pull in each buttress. If the base-plate extends in front of the face of the wall, thus forming an extended toe, as is frequently done with considerable economy and advantage, even that toe must be designed to withstand transverse bending at the wall line, and also shearing at that point. The application of these principles can best be understood by an illustration.

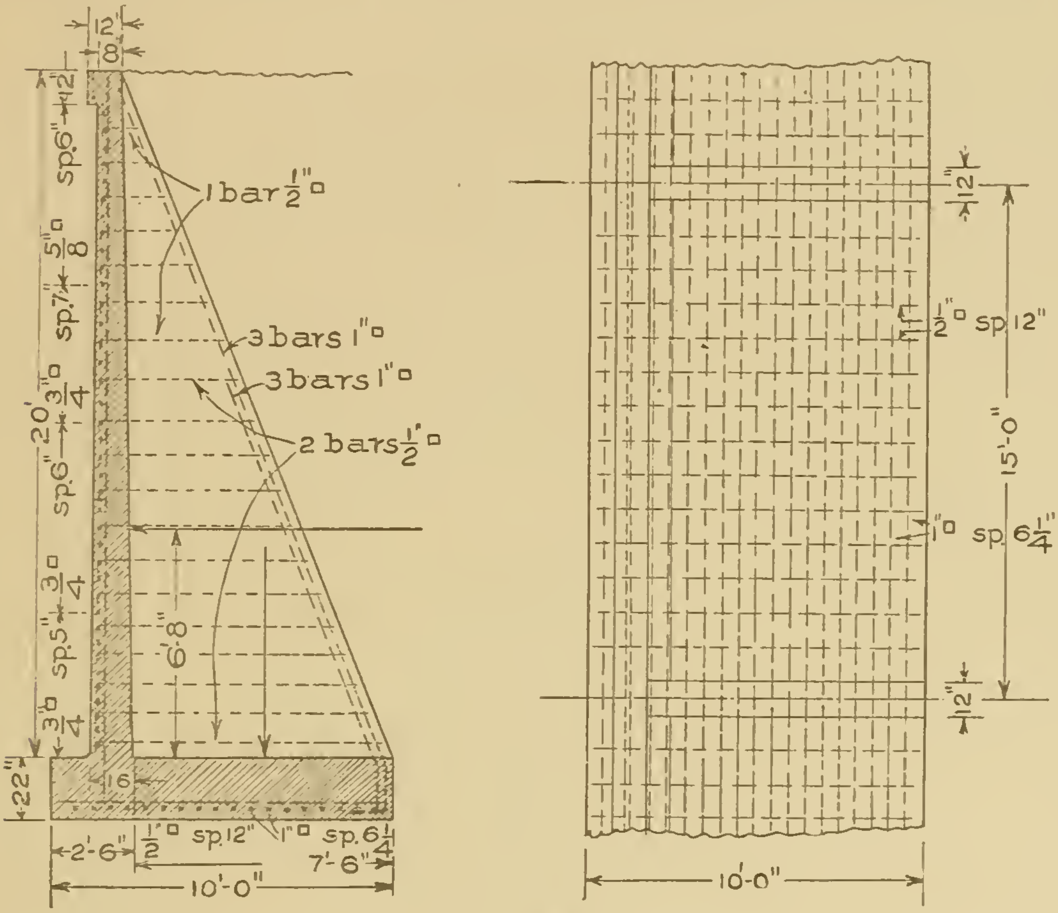


Fig. 43.

Numerical Example. Assume that it is required to design a retaining wall to withstand an ordinary earthwork pressure of 20 feet, the earth being level on top. We are at once confronted with the determination of the actual lateral pressure of the earthwork. Unfortunately, this is an exceedingly uncertain quantity, depending upon the nature of the soil, upon its angle of repose, and particularly upon its condition whether wet or dry. The *angle of repose* is the largest angle with the horizontal at which the material will stand without sliding down. A moment's consideration will show that this angle depends very largely on the condition of the material, whether wet or dry, etc. On this account any great refinement in these calculations is utterly useless.

Assuming that the back face of the wall is vertical, or practically so; that the upper surface of the earth is horizontal; and that the angle of repose of the material is 30°, the total pressure of the wall equals $\frac{1}{6}\ w\,h^2$, in which h is the total height of the wall, and w is the weight per unit volume of the earth. If the angle of repose is steeper than this, the pressure will be less. If the angle of repose is less than this, the fraction $\frac{1}{6}$ will be larger, but the unit weight of the material will *probably* be smaller. Assuming the weight at the somewhat excessive figure of 96 pounds per cubic foot, we can then say, as an ordinary rule, that the total pressure of the earth on a vertical strip of the wall one foot wide will equal $16\,h^2$, in which h is the height of the wall in feet. The average pressure, therefore, equals $16\,h$; and the maximum pressure at a depth of h feet equals $32\,h$. Applying this figure to our numerical example, we have a total pressure on a vertical strip one foot wide, of $16 \times 20^2 = 6{,}400$ pounds. The pressure at a depth of 20 feet $= 32 \times 20 = 640$ pounds.

It is usual to compute the thickness and reinforcement of a strip one foot wide running horizontally between two buttresses. Practically the strip at the bottom is very strongly reinforced by the base-plate, which runs at right angles to it; but if we design a strip at the bottom of the wall without allowing for its support from the base-plate, and then design all the strips towards the top of the wall in the same proportion, the upper strips will have their proper design, while the lower strip merely has an excess of strength. We shall assume in this case that the buttresses are spaced 15 feet from center to center. Then the load on a horizontal strip of face-plate 12 inches high, 15 feet long, and 19 feet 6 inches from the top, will be $15 \times 19.5 \times 32$, or

9,360 pounds. Multiplying this by 4, we have an ultimate load of 37,440 pounds. The span in inches equals 180. Then,

$$M_o = \frac{37,440 \times 180}{8} = 842,400 \text{ inch-pounds.}$$

Placing this equal to 397 $b\,d^2$, in which $b = 12$ inches, we find that $d^2 = 176.8$, and $d = 13.3$ inches. At one-half the height of the wall, the moment will equal one-half of the above, and the required thickness d would be 9.4 inches. The actual thickness at the bottom, including that required outside of the reinforcement, would therefore make the thickness of the wall about 16 inches at the bottom. At one-half the height, the thickness must be about 12 inches. Using a uniform taper, this would mean a thickness of 8 inches at the top.

The reinforcement at the bottom would equal .0084 × 13.3 = .112 square inch of metal per inch of height. Such reinforcement could be obtained by using $\frac{3}{4}$-inch bars spaced 5 inches apart. The reinforcement at the center of the height would be .0084 × 9.4 = .079 square inch per inch of width. This could be obtained by using $\frac{5}{8}$-inch bars about 5 inches apart, or by using $\frac{3}{4}$-inch bars about 7 inches apart. The selection and spacing of bars can thus be made for the entire height. While there is no method of making a definite calculation for the steel required in a vertical direction, it may be advisable to use $\frac{1}{2}$-inch bars spaced about 18 inches apart.

Base-Plate. We shall assume that the base-plate has a width of one-half the height of the wall, or is 10 feet wide. If the inner face of the face-plate is 2 feet 6 inches from the toe, the width of the base-plate sustaining the earth pressure is 7 feet 6 inches. The actual pressure on the base-plate is that due to the total weight of the earth. The upward pull on the buttresses is less than this, and is measured by the moment of the horizontal pressure tending to tip the wall over. To resist this overturning tendency, there must be a downward pressure on the plate whose moment equals the moment of the couple tending to turn the wall over. The pressure on the wall on a vertical strip one foot wide, as found above, is 6,400 pounds, which has a lever arm, about the center of the base of the face-plate, of 6 feet 8 inches. The vertical pressure to resist this will be applied at the center of the 7-foot 6-inch base, or 4 feet 5 inches from the center of the face-plate. The total necessary pressure will therefore be $\frac{6,400 \times 6.67}{4.42}$, or 9,653 pounds. This means an average pressure of 1,287 pounds per square foot. Making a similar calculation for this base-plate to that previously made for the face-plate, we find that the thickness $d = 19.1$ inches. This shows that our base-plate should have a total thickness of about 22 inches.

The amount of steel *per inch of width* of the slab equals $.0084 \times 19.1 = .160$ square inch. This can be provided by $\frac{7}{8}$-inch bars spaced $4\frac{3}{4}$ inches apart, or by 1-inch bars spaced $6\frac{1}{4}$ inches apart. This reinforcement will be uniform across the total width of the base-plate.

Buttresses. The total pressure on a vertical strip one foot wide is 6,400 pounds. For a panel of 15 feet, this equals 96,000 pounds; and its moment about the base of the wall equals 96,000 × 80 inches = 7,680,000 inch-pounds. If the tie-bars in the buttresses are placed about 3 inches from the face of the buttresses, their distance from the center of the base of the face wall will be about 89 inches. Therefore the tension in the bars in each buttress will equal $\frac{7,680,000}{89} = 86,292$ pounds.

Since the earth pressures considered above are actual pressures, we must here consider working stresses in the metal. Allowing 15,000 pounds' tension in the steel, it will require 5.75 square inches of steel for the tie-bars of each buttress. Six 1-inch square bars will more than furnish this area. Even these bars need not all be extended to the top of the buttress, since the tension is gradually being transferred to the face-plate.

The width of the buttress is not very definitely fixed. It must have enough volume to contain the bars properly, without crowding them. In this case, for the six 1-inch bars, we shall make the width 12 inches. At the base of the buttresses, these bars should be bent around bars running through the base-plate, so that the lower part of the buttress will be very thoroughly anchored into the base-plate. It is also necessary to tie the buttress to the face-plate. The amount of this tension is definitely calculated for each foot of height, from the total pressure on the face-plate in each panel for that particular foot of height. At a depth of 19.5 feet, we found a bursting pressure of 624 pounds per square foot, or 9,360 pounds on the 15-foot panel. This would therefore be the required bond between the buttress and the face-plate at a depth of 19.5 feet. With a working tension of 15,000 pounds per square inch, such a tension would be furnished by .624 square inch of metal. This equals .05 square inch of metal for each inch of height, and ½-inch bars spaced 5 inches apart will furnish this tension. The amount of this tension varies from the above, to zero at the top of the wall. This tension is usually provided by small bars, such as ½-inch bars, which are bent at a right angle so as to hook over the horizontal bars in the face-plate and run backward to the back of the buttress.

In the design described above, the extension of the toe beyond the face of the wall is so short that there is no danger that the toe will be broken off on account of either shearing or transverse stress. It is usually good policy to place some transverse bars in the base-plate which are perpendicular to the face of the wall, and to have them extend nearly to the point of the toe. No definite calculation can be made of the required number of these bars unless they are required to withstand transverse bending of the toe.

If there is any danger that the subsoil is liable to settle, and thus produce irregular stresses on the base-plate, a large reinforcement in this direction may prove necessary. It is good policy to place at least ½-inch bars every 12 inches through the base-plate, for the prevention of cracks; and this amount should be increased as the uncertainty in the stress in the base-plate increases. Although there are no definite stresses in the top of the wall, it is usual to make the thickness of the face-plate at least 6 inches at the top, and also to place a finishing cornice on top of the wall, somewhat as is shown in Fig. 48.

When the subsoil is very unreliable, it is even possible that there might be a tendency for the front and back of the base-plate to sink, and to break the base-plate by tension of the top. This can be resisted by bars in the upper part of the base-plate which are perpendicular to the wall.

Box Culverts. The permanency of concrete, and particularly reinforced concrete, has caused its adoption in the construction of culverts of all dimensions, from a cross-sectional area of a very few square feet, to that of an arch which might be more properly classified under the more common name "masonry arch." The smaller sizes can be constructed more easily, and with less expense for the forms, by giving them a rectangular cross-section. The question of foundations is solved most easily by making a concrete bottom, as well as side walls and top. The structure then becomes literally a "box." Its design consists in the determination of the external pressure exerted by the earth and of the required thickness of the concrete to withstand the pressure on the flat sides considered as slabs. The most uncertain part of the computation lies in the determination of the actual pressure of the earth. Under the heading, "Retaining Walls," this uncertainty was discussed.

One very simple method is to assume that the earth pressure is equivalent to that of a liquid having a unit weight equal to that

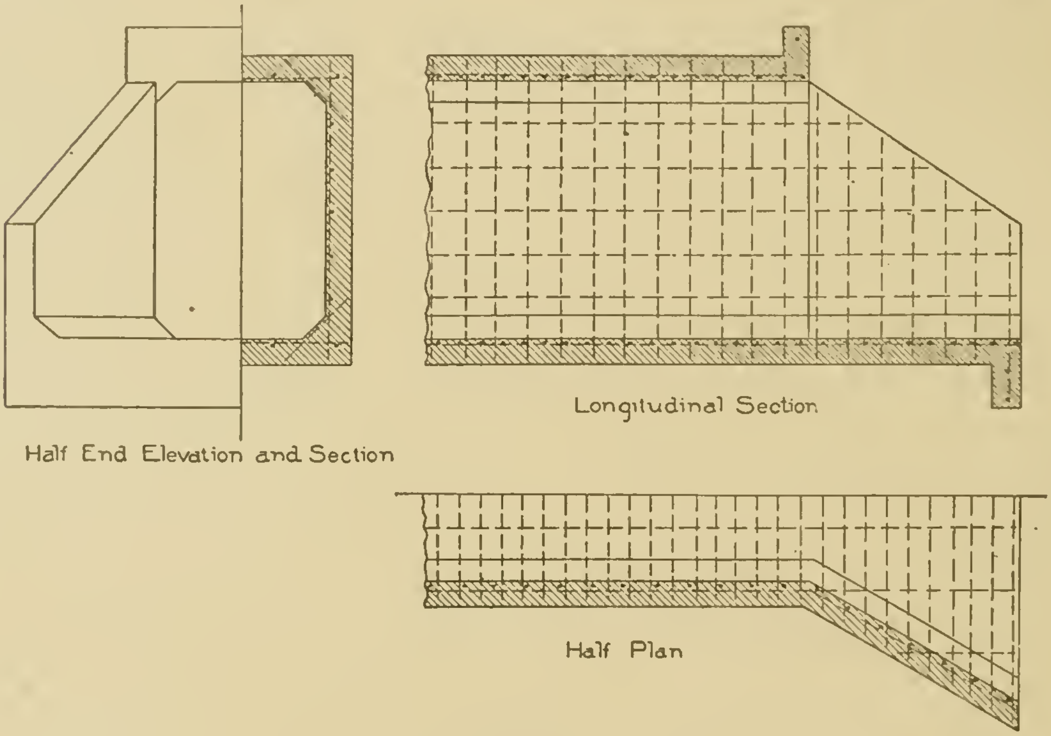


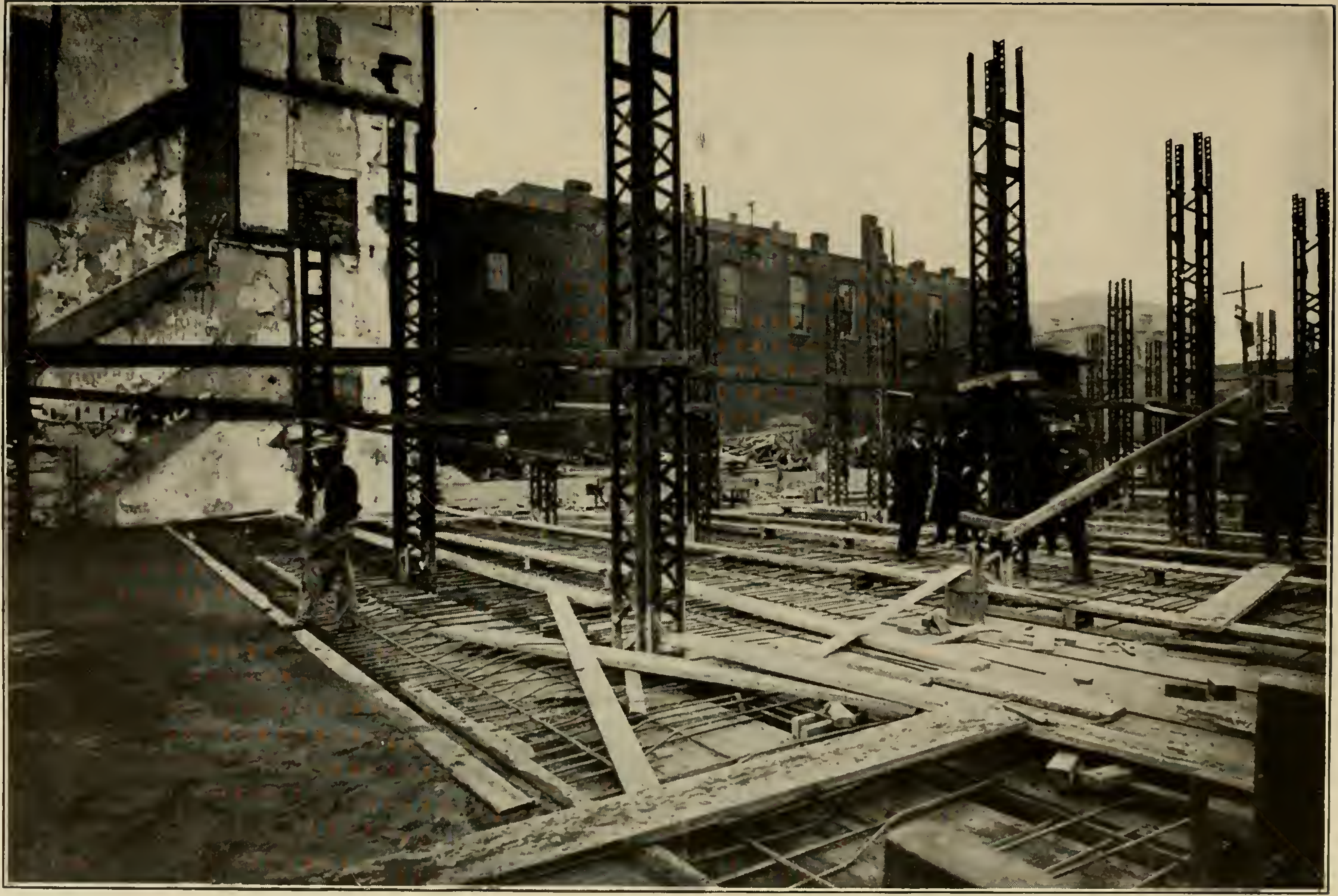
Fig. 49.

of the weight of a cubic foot of the earth, which is nearly 100 pounds. Under almost any circumstances, these figures would be sufficiently large, and perhaps very excessive. Calculations on such a basis are therefore certainly safe. If the pressure is computed on this basis, and a factor of safety of 2 is used, it is equivalent to an actual pressure of only one-half the amount (which is more probable) having a factor of 4. If the depth of the earth is quite large compared with the dimensions of the culvert, we may consider that the upward

MANUFACTURERS' FURNITURE EXCHANGE BUILDING, CHICAGO, ILL.

Wm. Ernest Walker, Architect; Condron & Sinks Co., Engineers, Chicago

Reinforced Concrete Construction, Brick Facing. Concreting of First Story Started October 10, 1906; Concrete Roof Completed December 27, 1906. Building is 70 feet by 170 feet.



MANUFACTURERS' FURNITURE EXCHANGE BUILDING, CHICAGO, ILL., SHOWING METHOD OF REINFORCED CONCRETE CONSTRUCTION.

Column Centers are 14 feet and 16 feet 9 inches. Columns Consist of 4 Angles Latticed, Filled in with Concrete, with the Angles Acting as Reinforcement for Same. Floor Construction, 14-Foot-Span Slabs on Reinforced Concrete Beams. Live Loads Figured on. First Floor, 150 lbs.; Second to Eighth Floors, 100 lbs.; Roof, 40 lbs. Test was made over an Area of 12 by 15 feet, with a Total Load of 55,780 lbs. plus Dead Load, making a Load of 310 lbs. per Square Foot plus Dead Load. The Deflection was Less than $\frac{1}{16}$ **Inch.**

pressure on the bottom, as well as the lateral pressure on the sides, is practically the same as the downward pressure on the top. If the bottom of the culvert is laid on rock, or on soil which is practically unyielding, there will be no necessity of considering that there is any upward pressure on the bottom slab tending to burst that slab upward. The softer the soil, the greater will be the tendency to transverse bending in the bottom slab.

Since the design of rectangular box culverts is purely an application of the equations for transverse bending, after the external pressures have been determined, no numerical example will here be given. These structures are not only reinforced with bars, considering the sides as slabs, but should also have bars placed across the corners, which will withstand a tendency for the section to collapse in case the pressure on opposite sides is unequal. They must also be reinforced with bars running longitudinally with the culvert. As in the other cases of longitudinal reinforcement, no definite design can be made for its amount. A typical cross-section for such a culvert is shown in Fig. 49. The longitudinal bars are indicated in this figure. They are used to prevent cracks owing to expansion or contraction, and also to resist any tendency to rupture which might be caused by a settling or washing-out of the subsoil for any considerable distance under the length of the culvert.

Arch Culverts. No attempt will here be made to explain the general theory of arches. A stone arch is always designed on the basis that there is no tension in the arch ring. The design is also based on the principle that the line of pressure within the arch ring shall always be such that there is some pressure on every part of each joint, which practically means that the line of pressure shall not at any point be outside the middle third of the arch ring. It is usually a simple matter so to design an arch ring that when the arch is uniformly loaded from end to end, either with a light load or with its maximum load, the line of pressure shall at all points be within the middle third of the arch ring; but when the load on the arch is eccentric—or, in other words, when one portion of the arch is heavily loaded, and the other parts of the arch have no load—the line of pressure may pass near the edge of the arch ring, or even entirely outside of it. This is especially true when the weight of the live load is large compared with the dead weight of the arch. An arch built of stone would certainly fail under such conditions. An arch built of plain concrete would probably also fail under such conditions, although the tensional strength of the concrete would permit a considerable variation of the line of pressure before failure would take place. If the arch is built of reinforced concrete, the tensional strength furnished by the bars will permit a very large variation in the line of pressure before failure will take place. This will permit the use of a very much thinner arch ring than would be safe for either

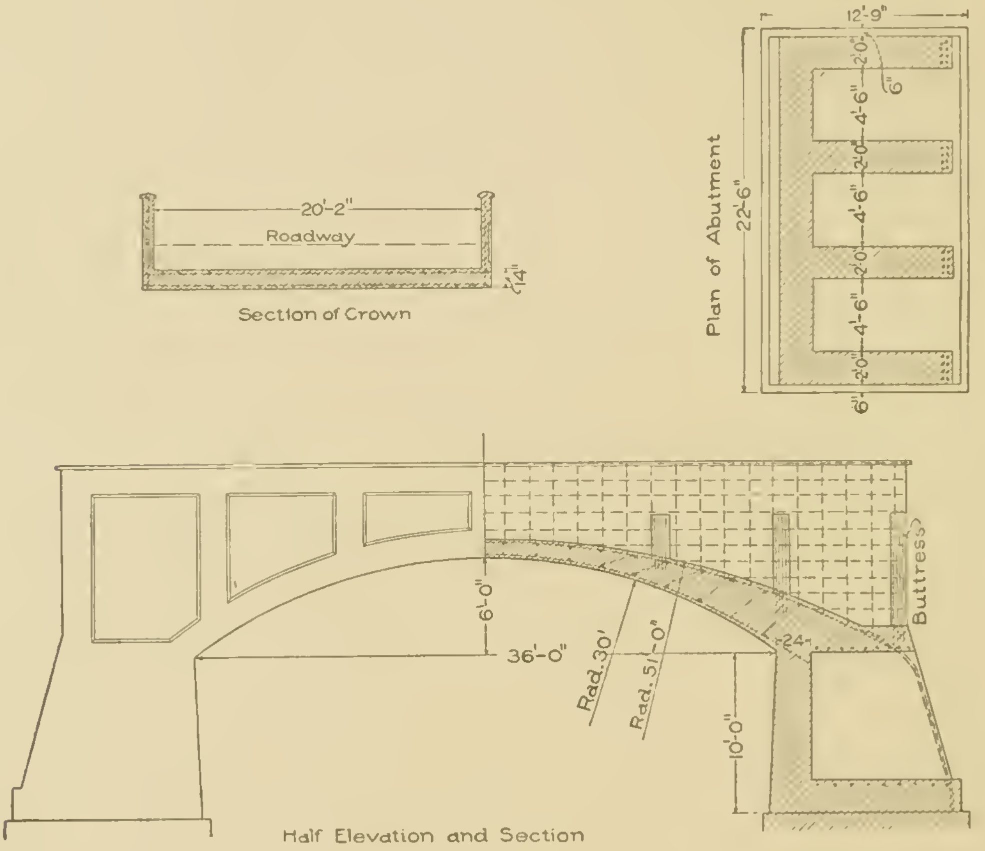


Fig. 50.

stone or plain concrete. Variations in the loading of an arch will cause such a change in the line of pressure, and such a variation in the place where a tendency to bending may occur, that it is usual to place two layers of bars, one slightly within the extrados of the arch, and the other slightly above the intrados. These bars are connected by cross-bars which resist the tendency to shearing. Bars are also placed parallel with the axis of the arch. These are illustrated in Fig. 50.

The design of the arch consists in the determination, according to the theory of elastic arches, of the maximum moment which can occur at any point of the arch, under any probable system of loading. The depth of the arch at that point, and the amount of steel required, can then be computed according to the principles of transverse bending previously laid down. Since it is impracticable to vary the amount of reinforcement at different sections of the arch, it is usual to compute the amount of reinforcement needed at the point where the requirement is the greatest, and to use such steel throughout the entire section of the arch. Almost the only variation from this occurs when additional bars are sometimes run from the abutment for several feet across the arch in order to provide for the very excessive moment that may occur near the abutment in some designs, that moment not being found under any conditions at or near the center of the arch. The amount of reinforcement which should be placed parallel with the axis of the arch is indefinite, as is the case with other forms of longitudinal reinforcement.

The centering for concrete arches is not materially different from that of the centering of any masonry arch, except in the fact that, since the concrete is usually a very wet mixture, the forms must be made with closer joints than would be required for a stone arch.

A very material saving can frequently be made in the amount of concrete in the abutments—especially when the soil is so soft that it cannot easily withstand the thrust of the arch—by connecting the two abutments by a concrete bottom in which are placed sufficient steel tie-rods to take up the thrust of the arch. Frequently there is a very considerable economy in this method, which has the added advantage that the bottom of the culvert will have a smooth surface, which will materially accelerate the flow of the water, and will even permit of a slight reduction in the cross-section of the arch opening. It is also possible to effect some economy in the amount of concrete required for the abutments, by using a skeleton form of construction, having a base-plate and buttresses somewhat similar to the skeleton design already shown for retaining walls (see Fig. 48). In such designs the pressure of the earth on the base-plate assists in furnishing the necessary anchorage for the abutments. The economy which is thus possible—and which is possible only because the structure is made of reinforced concrete—is very considerable.

Footings. When a definite load, such as a weight carried by a column, is to be supported on a subsoil whose bearing power has been estimated at some definite figure, the required area of the footing becomes a perfectly definite quantity, regardless of the method of construction of the footing. But with the area of the footing once determined, it is possible to effect considerable economy in the construction of the footing, by the use of reinforced concrete. An ordinary footing of masonry is usually made in a pyramidal form, although the sides will be stepped off instead of being made sloping. It may be approximately stated, that the depth of the footing below the base of the column, when ordinary masonry is used, must be practically equal to the width of the footing. The offsets in the masonry cannot ordinarily be made any greater than the heights of the various steps. Such a plan requires an excessive amount of masonry.

A footing of reinforced concrete consists essentially of a slab, which is placed no deeper in the ground than is essential to obtain a proper pressure from the subsoil. In the simplest case, the column is placed in the middle of the footing, and thus acts as a concentrated load in the middle of the plate. The mechanics of such a problem are somewhat similar to those of a slab supported on four sides and carrying a concentrated load in the center, with the very important exception, that the resistance, instead of being applied merely at the edges of the slab, is uniformly distributed over the entire surface. Since the column has a considerable area, and the slab merely overlaps the column on all sides, the common method is to consider the overlapping on each side to be an inverted cantilever carrying a uniformly distributed load, which is in this case an upward pressure. The maximum moment evidently occurs immediately below each vertical face of the column. At the extreme outer edge of the slab the moment is evidently zero, and the thickness of the slab may therefore be reduced considerably at the outer edge. The depth of the slab, and the amount of reinforcement, which is of course placed near the bottom, can be determined according to the usual rules for obtaining a moment. This can best be illustrated numerically.

Example. Assume that a load of 252,000 pounds is to be carried by a column, on a soil which consists of hard, firm gravel. Such soil will ordinarily safely carry a load of 7,000 pounds per square foot. On this basis, the area of the footing must be 36 square feet, and therefore a footing 6 feet square will answer the purpose. A concrete column 24 inches square will safely carry such a loading. Placing such a column in the middle of a footing will leave an offset 2 feet broad outside each face of the column. We may consider a section of the footing made by passing a vertical plane through one face of the column. This leaves a block of the footing 6 feet long and 2 feet wide, on which there is an upward pressure of 12 × 7,000 = 84,000 pounds. The center of pressure is 12 inches from the section, and the moment is therefore 12 × 84,000 = 1,008,000 inch-pounds. Multiplying this by 4, we have 4,032,000 inch-pounds as the ultimate moment. Applying Equation **13**, we place this equal to $397\,b\,d^2$, in which b = 72 inches. Solving this for d, we have d = 11.9 inches. A total thickness of 15 inches would therefore answer the purpose. The amount of steel required per inch of width = $.0084\,d = .0084 \times 11.9 = .100$ square inch of steel per inch of width. Therefore $\frac{3}{4}$-inch bars, spaced 5.6 inches apart, will serve the purpose. A similar reinforcing of bars should be placed perpendicularly to these bars.

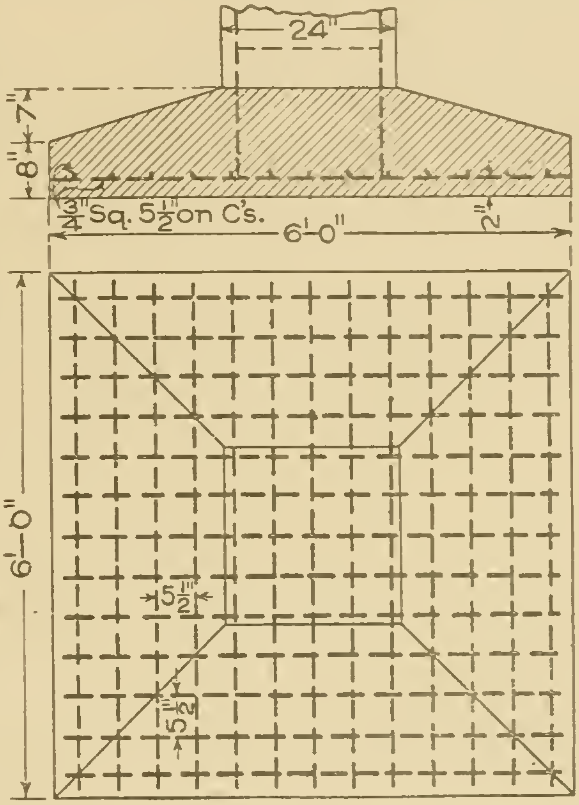


Fig. 51

The above very simple solution would be theoretically accurate in the case of an offset 2 feet wide for the footing of a wall of indefinite length, assuming that the upward pressure was 7,000 pounds per square foot. The development of such a moment uniformly along the section of our square footing, implies a resistance to bending at the outer edges of the slab which will not actually be obtained. The moment will certainly be greater under the edges of the column. On the other hand, we have used bars in both directions. The bars passing under the column in each direction are just such as are required to withstand the moment produced by the pressure on that part of the footing directly in front of each face of the column. It may be considered that the other bars have their function in tying the two systems into one plate whose several parts mutually support one another. If further justification of such a method is needed, it may be said that experience has shown that it practically fulfils its purpose.

When a simple footing supports a single column, the center of pressure of the column must pass vertically through the center of gravity of the footing, or there will be dangerous transverse stresses in the column, as discussed later. But it is sometimes necessary to support a column on the edge of a property line when it is not permissible to extend the foundations beyond the property line. In such a case, a simple footing is impracticable. The method of such a solution is indicated in Fig. 52, without numerical computation. The nearest interior column (or even a column on the opposite side of the building, if the building be not too wide) is selected, and a combined footing is constructed under both columns. The weight on both columns is computed. If the weights are equal, the center of

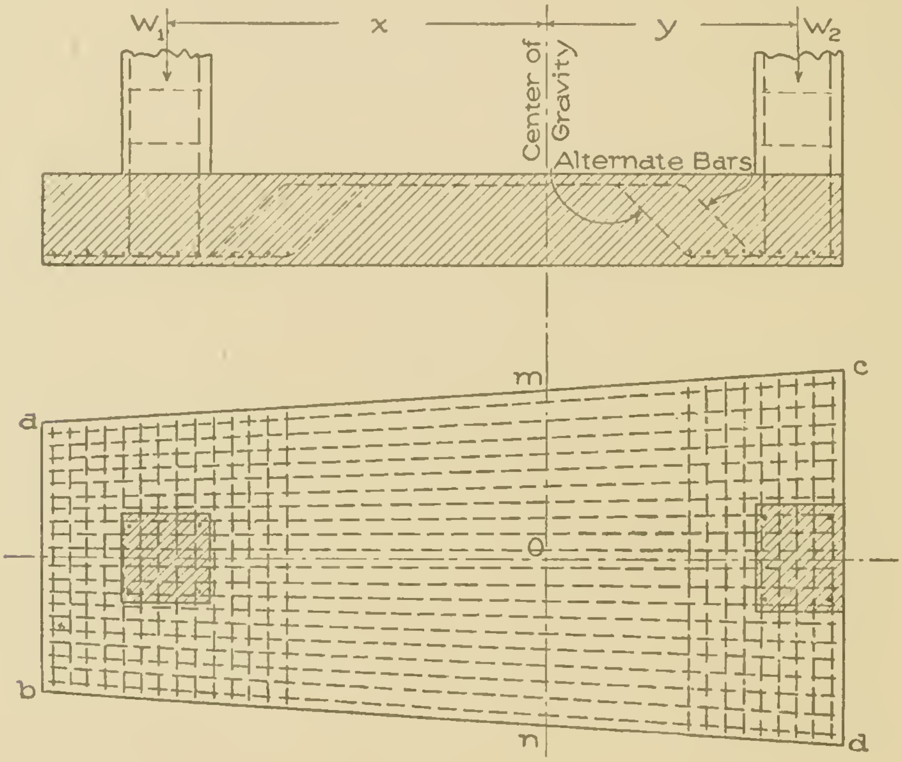


Fig. 52.

gravity is half-way between them; if unequal, the center of gravity is on the line joining their centers, and at a distance from them such that (see Fig. 52) $x:y :: W_2 : W_1$. In this case, evidently, W_2 is the greater weight. The area $abcd$ must fulfil two conditions:

(1) The area must equal the total loading ($W_1 + W_2$), divided by the allowable loading per square foot; and

(2) The center of gravity must be located at O.

An analytical solution of the relative and absolute values of ab and cd which will fulfil the two conditions, is very difficult, and fortunately is practically unnecessary. If x and y are equal, $abcd$ is a rectangle. If W_2 is greater than $2\ W_1$, then y will be less than $\frac{1}{2}x$; and even a triangle with the vertex under the column W_1, would not fulfil the condition. In fact, if W_1 is very small compared with W_2, it might be impracticable to obtain an area sufficiently large to sustain the weight. The proper area can be determined by a few trials, with sufficient accuracy for the purpose.

The footing must be considered as an inverted beam at the section mn, where the moment $= W_2y + W_2x$. The width is mn; and the required depth and the area of the steel must be computed by the usual methods. The bars will here be in the top of the footing, but will be bent down to the bottom under the columns, as shown in Fig. 52. The cross-bars under each column will be designed, as in the case of the simple footing, to distribute the weight on each column across the width of the footing, and to transfer the weight to the longitudinal bars.

Vertical Walls. Vertical walls which are not intended to carry any weight, are sometimes made of reinforced concrete. They are then called *curtain walls*, and are designed merely to fill in the panels between the posts and girders which form the skeleton frame of the building. When these walls are interior walls, there is no definite stress which can be assigned to them, except by making assumptions that may be more or less unwarranted. When such walls are used for exterior walls of buildings, they must be designed to withstand wind pressure. This wind pressure will usually be exerted as a pressure from the outside tending to force the wall inward; but if the wind is in the contrary direction, it may cause a lower atmospheric pressure on the outside, while the higher pressure of the air within the building will tend to force the wall outward. It is improbable, however, that such a pressure would ever be as great as that tending to force the wall inward. Such walls may be designed as slabs carrying a uniformly distributed load, and supported on all four sides. If the panels are approximately square, they should have bars in both directions, and should be designed by the same method as "slabs reinforced in both directions," as has been previously explained. If the vertical posts are much closer together than the height of the floor, as sometimes occurs, the principal reinforcing bars should be horizontal, and the walls should be designed as slabs having a span equal to the distance between the posts. Some small bars spaced about 2 feet apart should be placed vertically to prevent shrinkage. The pressure of the wind corresponding to the loading of the slab, is usually considered to be 30 pounds per square foot, although the actual wind pressure will very largely depend on local conditions, such as the protection which the building receives from surrounding buildings. A pressure of thirty pounds per square foot is usually sufficient; and a slab designed on this basis will usually be so thin, perhaps only 4 inches, that it is not desirable to make it any thinner. Since designing such walls is such an obvious application of the equations and problems already solved in detail, no numerical illustration will here be given.

Wind Bracing. The practical applications of the principles of reinforced concrete which have already been discussed, have been almost exclusively those required for sustaining vertical loads; but a structure consisting simply of beams, girders, slabs, and columns *may* fall down, like a house of cards, unless it is provided with lateral bracing to withstand wind pressure and any lateral forces tending to turn it over. The necessary provision for such stresses is usually made by placing *brackets* in the angles between posts and girders, as has been illustrated in Fig. 46. These brackets are reinforced with bars which will resist any tensile stress on the brackets. The compressive strength of concrete may be relied on to resist a tendency to crush the brackets by compression. Usually such brackets will occur in pairs at each end of a beam supported on two columns. If we consider that any given moment is to be divided equally between two brackets, then, if we are to have a working tension of 15,000 pounds per square inch in the steel, and a working compression of 500 pounds per square inch in the concrete, the area of the concrete must be 30 times the area of the steel. But since the outer face of the concrete will have practically twice the compression of the concrete at the angle of the beam and column, and since the maximum of 500 pounds per square inch must not be exceeded, we must have twice that area of concrete; or, in other words, the area of the concrete from the point of the angle down to the face must be 60 times the area of the steel.

Although these brackets are frequently put in without any definite design, it is possible to make some sort of computation, especially when a building is directly exposed to wind pressure, by computing the moment of the wind pressure. For example, if a building is 100 feet long and 50 feet high, and is subjected to a wind pressure of 30 pounds per square foot, the total wind pressure will be 50 × 100 × 30 = 150,000 pounds. Considering the center of pressure as applied at half the height, this would give a moment about the base of the building, of 150,000 × 25 = 3,750,000 foot-pounds = 45,000,000 inch-pounds. If this 100-foot building had eight lines of columns with a pair of brackets on each line, and was four stories high, there would be 64 such brackets to resist wind pressure. Each bracket would therefore be required to resist $\frac{1}{64}$ of 45,000,000 inch-pounds, or about 700,000 inch-pounds. We shall assume that the bracket will have a depth of 25 inches, from the intersection of the center lines of the column and the beam to the steel near the face of the bracket. Then, since each bracket must withstand a moment of 700,000 inch-pounds, the stress in the steel will be 700,000 ÷ 25 = 28,000 pounds. If the actual stress in the steel is 15,000 pounds per square inch, this would require 1.87 square inches of steel, which would be more than supplied by four $\frac{3}{4}$-inch square bars. If these brackets were 12 inches wide and 25 inches deep, the area of concrete is 300 square inches, which is 160 times the area of the steel. There is, therefore, an ample amount of concrete to withstand compression, on the part of those brackets which are subject to compression rather than tension. It is probable that the above calculation is excessive on the side of safety, since it is quite improbable that such a broad area would ever be subject to a pressure of 30 pounds per square foot over the whole area. The method of calculation also ignores the fact that the monolithic character of a reinforced concrete structure furnishes a very considerable resistance at the junction of columns and girders, and that they should not by any means be considered as if they were "pin-connected" structures, which would require that the whole of the lateral stiffening should be supplied by these brackets. Nevertheless these brackets must be designed according to some such method.

COLUMNS

Methods of Reinforcement. The laws of mechanics, as well as experimental testing on full-sized columns of various structural materials, show that very short columns, or even those whose length is ten times their smallest diameter, will fail by crushing or shearing of the material. If the columns are very long, say twenty or more times their smallest diameter, they will probably fail by bending, which will produce an actual tension on the convex side of the column. The line of division between long and short columns is practically very uncertain, owing to the fact that the center line of pressure of a column is frequently more or less eccentric because of irregularity of the bearing surface at top or bottom. Such an eccentric action will cause buckling of the column even when its length is not very great. On this account, it is always wise (especially for long columns) to place reinforcing bars within the column. The reinforcing bars consist of longitudinal bars (usually four, and sometimes more with the larger columns), and bands of small bars spaced about 12 or 18 inches apart vertically, which bind together the longitudinal bars. The longitudinal bars are used for the purpose of providing the necessary transverse strength to prevent buckling of the column. As it is practically impossible to develop a satisfactory theory on which to compute the required tensional strength in the convex side of a column of given length, without making assumptions which are themselves of doubtful accuracy, no exact rules for the sizes of the longitudinal bars in a column will be given. The bars ordinarily used vary from $\frac{1}{2}$ inch square to 1 inch square; and the number is usually four, unless the column is very large (400 square inches or larger) or is rectangular rather than square. It has been claimed by many, that longitudinal bars in a column may actually be a source of danger, since the buckling of the bars outward may tend to disintegrate the column. This buckling can be avoided, and the bars made mutually self-supporting, by means of the bands which are placed around the column. These bars are usually $\frac{1}{4}$-inch or $\frac{3}{8}$-inch round or square bars. The specifications of the Prussian Public Works for 1904 require that these horizontal bars shall be spaced a distance not more than 30 times their diameter, which would be 7½ inches for ¼-inch bars, and 11¼ inches for ⅜-inch bars. The bands in the column are likewise useful to resist the bursting tendency of the column, especially when it is short. They will also reinforce the column against the tendency to shear, which is the method by which failure usually takes place. The angle between this plane of rupture and a plane perpendicular to the line of stress, is stated to be 60°. If, therefore, the bands are placed at a distance apart equal to the smallest diameter of the column, any probable plane of rupture will intersect one of the bands, even if the angle of rupture is somewhat smaller than 60°.

The unit working pressure permissible in concrete columns is usually computed at from 350 to 500 pounds per square inch. The ultimate compression for transverse stresses for 1:3:6 concrete has been taken at 2,000 pounds per square inch. With a factor of 4, this gives a working pressure of 500 pounds per square inch; but the ultimate stress in a column of plain concrete is generally less than 2,000 pounds per square inch. Tests of a large number of 12 by 12-inch plain concrete columns showed an ultimate compressive strength of approximately 1,000 pounds per square inch; but such columns generally begin to fail by the development of longitudinal cracks. These would be largely prevented by the use of lateral reinforcement or bands. Therefore the use of 500 pounds per square inch, as a working stress for columns which are properly reinforced, may be considered justifiable although not conservative.

Design of Columns. It may be demonstrated by theoretical mechanics, that if a load is jointly supported by two kinds of material with dissimilar elasticities, the proportion of the loading borne by each will be in a ratio depending on their relative areas and moduli of elasticity. The formula for this may be developed as follows:

C = Total unit compression upon concrete and steel in pounds per square inch = Total load divided by the combined area of the concrete and the steel;

c = Unit compression in the concrete, in pounds per square inch;

s = Unit compression in the steel, in pounds per square inch;

p = Ratio of area of steel to total area of column;

$r = \frac{E_s}{E_c}$ = Ratio of the moduli of elasticity;

ϵ_s = Deformation per unit of length in the steel;

ϵ_c = Deformation per unit of length in the concrete;
A_s = Area of steel;
A_c = Area of concrete.

The total compressive force in the concrete = $A_c \times c$; and that in the steel = $A_s \times s$.

The sum of these compressions = the total compression; and therefore,

$$C\,(A_c + A_s) = A_c\,c + A_s\,s.$$

The actual lineal compression of the concrete = that of the steel; therefore,

$$\frac{c}{E_c} = \frac{s}{E_s}\,.$$

From this equation, since $r = \frac{E_s}{E_c}$, we may write the equation $rc = s$. Solving the above equation for C, we obtain:

$$C = \frac{A_c\,c + A_s\,s}{A_c + A_s}.$$

Substituting the value of $s = rc$, we have:

$$C = c\,\Big(\frac{A_c + A_s\,r}{A_c + A_s}\Big) = c\,\Big(\frac{A_s + A_c - A_s + A_s\,r}{A_c + A_s}\Big)$$

If p = the ratio of cross-section of steel to the *total* cross-section of the column, we have:

$$p = \frac{A_s}{A_c + A_s}\,.$$

Substituting this value of $\frac{A_s}{A_c + A_s}$ in the above equation, we may write:

$$C = c\,(1 - p + pr)\,.$$

Solving this equation for p, we obtain:

$$p = \frac{C - c}{c\,(r - 1)} \quad \text{...} \quad (16)$$

Example 1. A column is designed to carry a load of 160,000 pounds. If the column is made 18 inches square, and the load per square inch to be carried by the concrete is limited to 400 pounds, what must be the percentage of the steel, and how much steel would be required?

Answer. A column 18 inches square has an area of 324 square inches. Dividing 160,000 by 324, we have 494 pounds per square inch as the total unit compression upon the concrete and the steel, which is C in the above formula. Assume that the concrete is 1:3:6 concrete, and that the ratio of the moduli of elasticity (r) is therefore 12. Substituting these values in Equation 16, we have:

$$p = \frac{494 - 400}{400\ (12 - 1)} = .0214.$$

Multiplying this ratio by the total area of the column, 324 square inches, we have 6.93 square inches of steel required in the column. This would very nearly be provided by four bars $1\frac{1}{4}$ inches square. Four round bars $1\frac{1}{2}$ inches in diameter would give an excess in area. Either solution would be amply safe under the circumstances, provided the column was properly reinforced with bands.

Example 2. A column 16 inches square is subjected to a load of 115,000 pounds, and is reinforced by four $\frac{7}{8}$-inch square bars beside the bands. What is the actual compressive stress in the concrete per square inch?

Answer. Dividing the total stress (115,000) by the area (256), we have the combined unit stress $C = 449$ pounds per square inch. By inverting one of the equations above, we can write

$$c = \frac{C}{1 - p + r\,p}.$$

In the above case, the four $\frac{7}{8}$-inch bars have an area of 3.06 square inches; and therefore,

$$p = \frac{3.06}{256} = .012;\ r = 12.$$

Substituting these values in the above equation, we may write:

$$c = \frac{449}{1 - .012 + (.012 \times 12)} = \frac{449}{1.132} = 397 \text{ pounds per square inch.}$$

The net area of the concrete in the above problem is 252.94 square inches. Multiplying this by 397, we have the total load carried by the concrete, which is 100,117 pounds. Subtracting this from 115,000 pounds, the total load, we have 14,885 pounds as the compressive stress carried by the steel. Dividing this by 3.06, the area of the steel, we have 4,864 pounds as the unit compressive stress in the steel. This is practically twelve times the unit compression in the concrete, which is an illustration of the fact that if the compression is shared by the two materials in the ratio of their moduli of elasticity, the unit stresses in the materials will be in the same ratio. This unit stress in the steel is about one-third of the working stress which may properly be placed on the steel. It shows that we cannot economically use the steel in order to reduce the area of the concrete, and that the only object in using steel in the columns is in order to protect the columns against buckling, and also to increase their strength by the use of bands.

It sometimes happens that in a building designed to be structurally of reinforced concrete, the column loads in the columns of the lower story may be so very great that concrete columns of sufficient size would take up more space than it is desired to spare for such a purpose. For example, it might be required to support a load of 320,000 pounds on a column 18 inches square. If the concrete (1:3:6) is limited to a compressive stress of 400 pounds per square inch, we may solve for the area of steel required, precisely as was done in example 1. We would find that the required percentage of steel was 13.4 per cent, and that the required area of the steel was therefore 43.3 square inches. But such an area of steel could carry the entire load of 320,000 pounds without the aid of the concrete, and would have a compressive unit stress of only 7,400 pounds. In such a case, it would be more economical to design a steel column to carry the entire load, and then to surround the column with sufficient concrete to fireproof it thoroughly. Since the stress in the steel and the concrete are divided in proportion to their relative moduli of elasticity, which is usually about 10 or 12, we cannot develop a working stress of, say, 15,000 pounds per square inch in the steel, without at the same time developing a compressive stress of 1,200 to 1,500 pounds in the concrete, which is objectionably high as a working stress.

Effect of Eccentric Loadings of Columns. It is well known that if a load on a column is eccentric, its strength is considerably less than when the resultant line of pressure passes through the axis of the column. The theoretical demonstration of the amount of this eccentricity depends on assumptions which may or may not be found in practice. The following formula is given without proof or demonstration, in Taylor & Thompson's Treatise on Concrete:

Let c = Eccentricity of load;
b = Breadth of column;
f = Average unit pressure;
f' = Total unit pressure of outer fiber nearest to line of vertical pressure.

Then,

$$f' = f\left(1 + \frac{6c}{b}\right) \qquad (17)$$

As an illustration of this formula, if the eccentricity on a 12-inch column were 2 inches, we would have $b = 12$, and $e = 2$. Substituting these values in Equation **17**, we would have $f' = 2f$, which means that the maximum pressure would equal twice the average pressure. In the extreme case, where the line of pressure came to the outside of the column, or when $e = \frac{1}{2} b$, we would have that the maximum pressure on the edge of the column would equal four times the average pressure.

Any refinements in such a calculation, however, are frequently overshadowed by the uncertainty of the actual location of the center of pressure. A column which supports two equally loaded beams on each side, is probably loaded more symmetrically than a column which supports merely the end of a beam on one side of it. The best that can be done is arbitrarily to lower the unit stress on a column which is probably loaded somewhat eccentrically.

STRENGTH OF TEE-BEAMS

When concrete beams are laid in conjunction with overlying floor-slabs, the concrete for both the beams and the slabs being laid in one operation, the strength of such beams is very much greater than their strength considered merely as plain beams, even though we compute the depth of the beams to be equal to the total depth from the bottom of the beam to the top of the slab. An explanation of this added strength may be made as follows:

If we were to construct a very wide beam with a cross-section such as is illustrated in Fig. 53, there is no hesitation about calculating such strength as that of a plain beam whose width is b, and whose effective depth to the reinforcement is d. Our previous study in plain beams has shown us that the steel in the bottom of the beam takes care of practically all the tension; that the neutral axis of the beam is somewhat above the center of its height; that the only work of the concrete below the neutral axis is to transfer the stress in the steel to

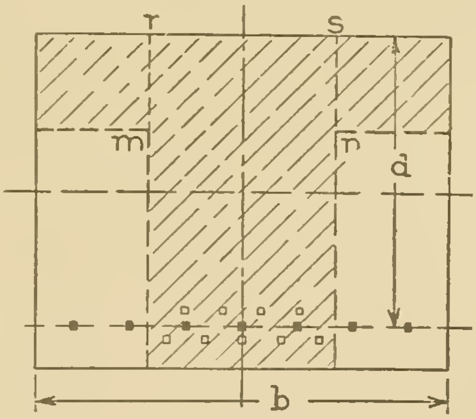


Fig. 53. Tee-Beam in Cross-Section.

the concrete in the top of the beam; and that even in this work it must be assisted somewhat by stirrups or by bending up the steel bars. If, therefore, we cut out from the lower corners of the beam two rectangles, as shown by the unshaded areas, we are saving a very large part of the concrete, with very little loss in the strength of the beam, provided we can fulfil certain conditions. The steel, instead of being distributed uniformly throughout the bottom of the wide beam, is concentrated into the comparatively narrow portion which we shall hereafter call the *rib* of the beam. The concentrated tension in the bottom of this rib must be transferred to the compression area at the top of the beam. We must also design the beam so that the shearing stresses in the plane (*mn*) immediately below the slab shall not exceed the allowable shearing stress in the concrete. We must also provide that failure shall not occur on account of shearing in the vertical planes (*m r* and *n s*) between the sides of the beam and the flanges. In computing the compression in the fibers in the upper part of the simple beam, it is assumed that all fibers at the same distance above the neutral axis are stressed equally. The same assumption is sometimes made when developing the formula for tee-beams. Such an assumption is substantially true in the case of the simple beam, but is practically untrue (and perhaps dangerously so) in the case of tee-beams with wide flanges. The maximum compression is evidently found immediately above the rib of the beam, while the compressive stress probably diminishes on each side of the rib. Fig. 54 gives a graphical representation of the diminution in intensity of pressure in the flange. When the distance between adjacent beams is comparatively great, there is probably (and in fact usually) a considerable portion of the slab between consecutive beams which is practically unaffected by the compression required for the top of each tee-beam. Since this compression is concentrated above the rib of each tee-beam, the work must be so designed that the *maximum* pressure (instead of the *average* pressure) does not exceed the safe working value.

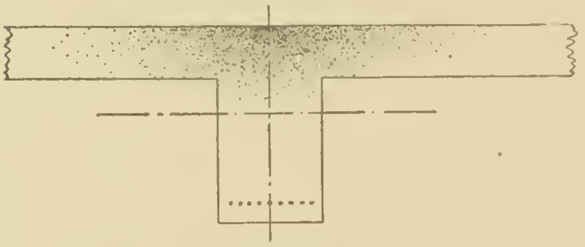
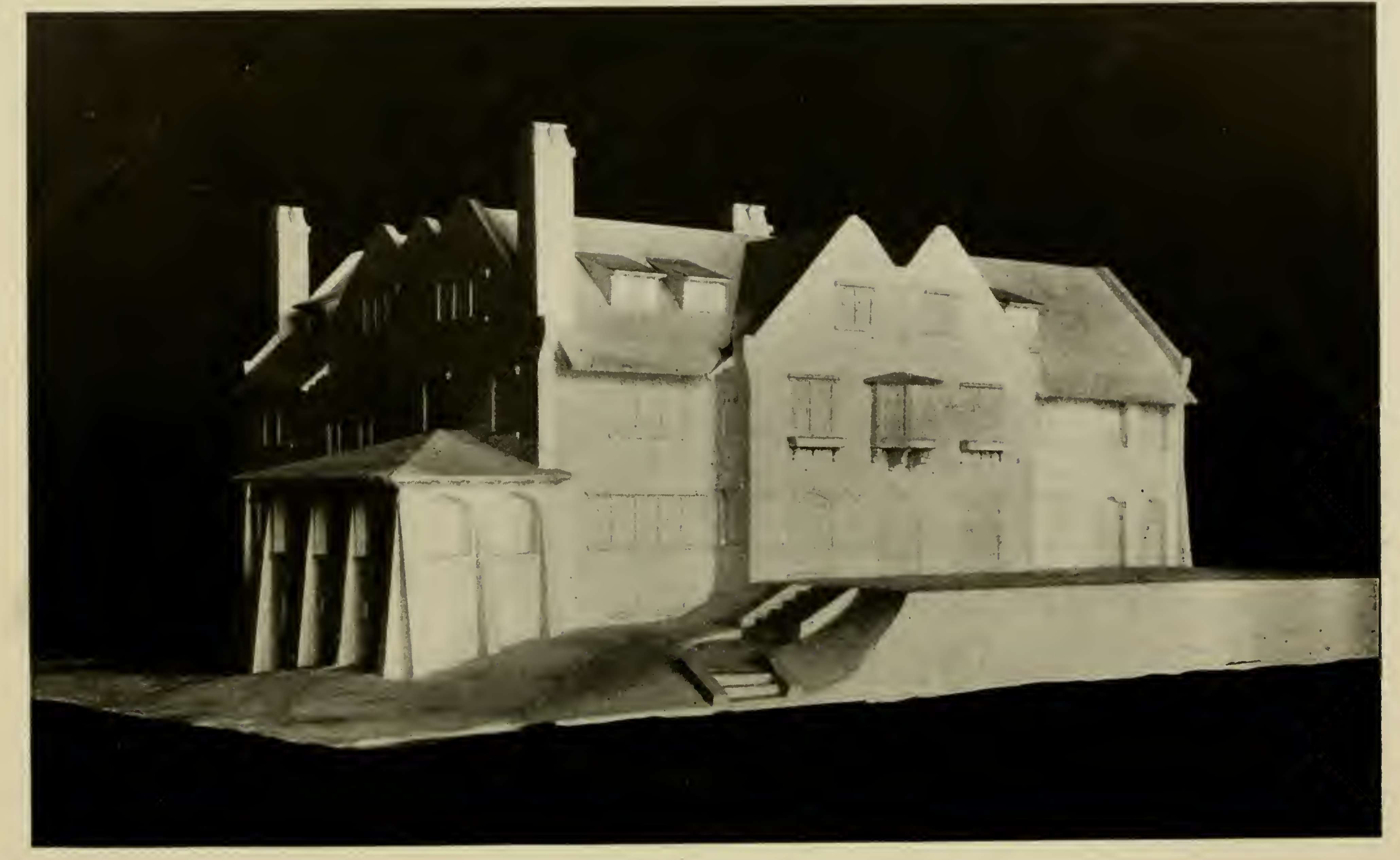


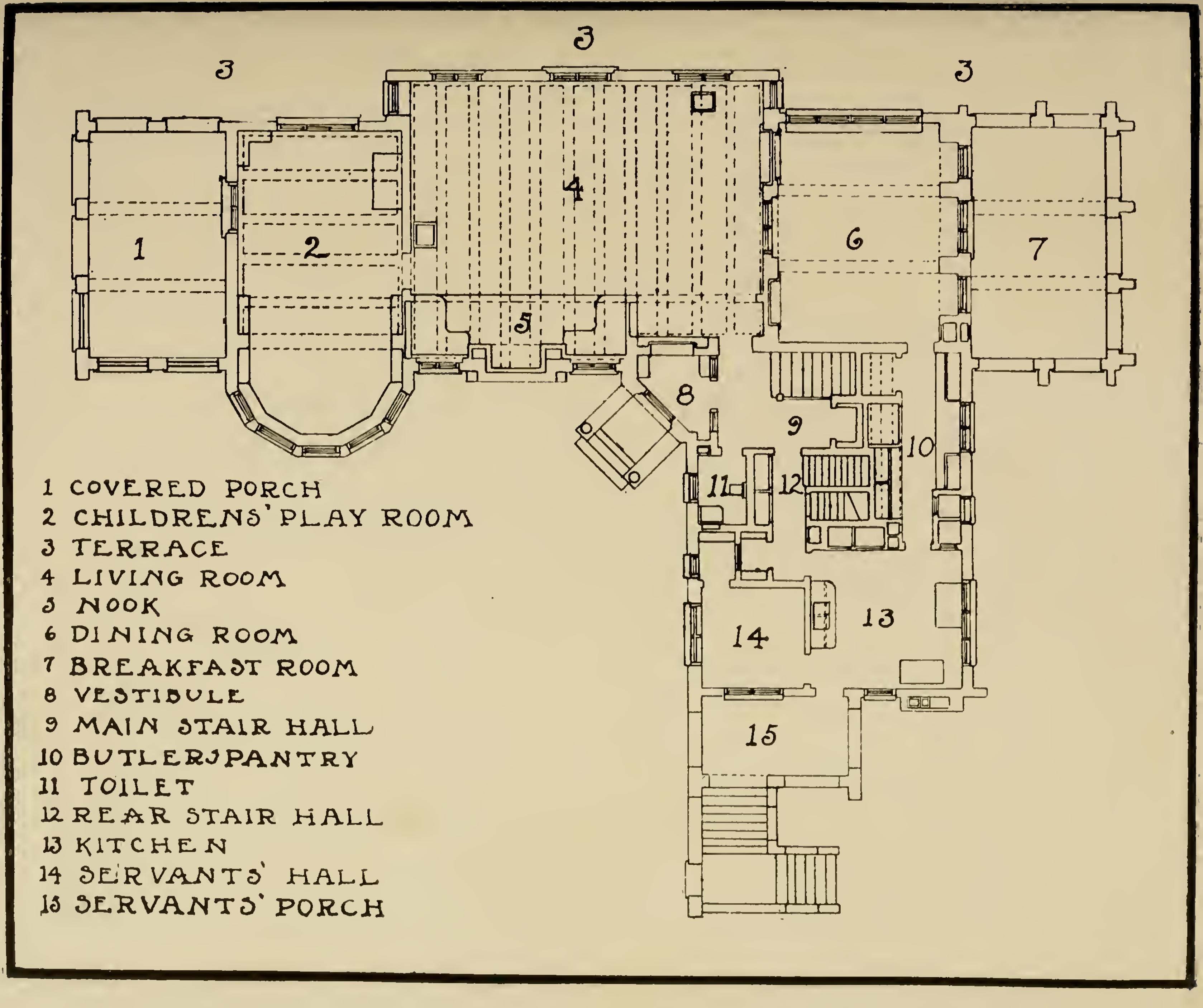
Fig. 54. Graphical Representation of Diminution in Intensity of Pressure in Flange.



ARCHITECTS' MODEL OF RESIDENCE FOR MR. FRED PABST, ON OCONOMOWOC LAKE, WIS.

Fernekes & Cramer, Architects, Milwaukee, Wis.: Newton Engineering Co., Engineers.

All Walls and Partitions are of Reinforced Concrete. The Exterior Walls will not be Plastered, but are to have a Hammered Finish. Red Tile Roof. Cost, about $40,000. Building is to be Completed in the Fall of 1907.



FIRST-STORY PLAN OF RESIDENCE FOR MR. FRED PABST, ON OCONOMOWOC LAKE, WIS.

Fernekes & Cramer, Architects, Milwaukee, Wis., Newton Engineering Co., Engineers.

All Exterior and Interior walls and Partitions are of Reinforced Concrete (Kahn System); Floors and Roof are of Steel and Hollow Tile. The Terrace (3) and Breakfast Room (7) Overlook Oconomowoc Lake. For Second-Story Plan, See Page 139.

Let us consider a tee-beam such as is illustrated in Fig. 55. If we were to insert an excessively large amount of steel in the lower part of the rib, we could probably develop a compression in the flange which would require a very wide flange. But the beam would probably fail by shearing along the horizontal plane immediately under the flange. In order to have the most economical design, which means that the beam shall be equally strong in every respect, or, in other words, that it shall be equally liable to failure in several ways when loaded to its ultimate load, we must obtain a relation between the total compression in the flange and the required shearing strength in the rib immediately under the flange. In the lower part of Fig. 55, is represented one-half of the length of the flange, which is considered to have been separated from the rib. Following the usual method of considering this as a free body in space, acted on by external forces and by such internal forces as are necessary to produce equilibrium, we find that it is acted on at the left end by the abutment reaction, which is a vertical force, and also by a vertical load on top. We may consider P' to represent the summation of all compressive forces acting on the flange at the center of the beam. In order to produce equilibrium there must be a shearing force acting on the underside of the flange. We represent this force by S_h. Since these two forces are the only horizontal forces, or forces with horizontal components, which are acting on this free body in space, P' must equal S_h. Let us consider z to represent the ultimate shearing force per unit of area. We know from the laws of mechanics, that, with a uniformly distributed load on the beam, the shearing force is maximum at the ends of the beam, and diminishes uniformly towards the center, where it is zero. Therefore the *average* value of the unit shear for the half-

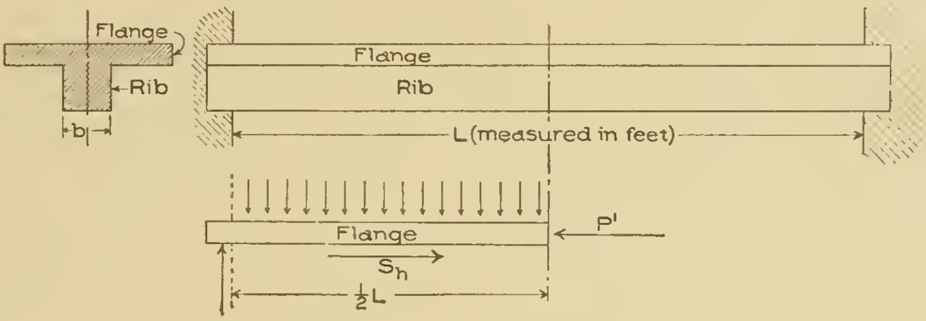


Fig. 55. Tee-Beam.

length of the beam, must equal $\frac{1}{2} z$. As before, we represent the width of the rib by b. For convenience in future computations, we shall consider L to represent the length of the beam measured in *feet.* All other dimensions are measured in inches. Therefore the total shearing force along the lower side of the flange, will be:

$$S_h = \tfrac{1}{2} z \times b \times \tfrac{1}{2} L \times 12 = 3\, b\, z\, L \ldots\ldots\ldots\ldots (18)$$

There is also a possibility that a beam may fail in case the flange (or the slab) is too thin; but the slab is always reinforced by bars which are transverse to the beam, and the slab will be placed on both sides of the beam, giving two shearing surfaces. Beams supporting a slab on only one side, should be computed as plain beams. Therefore, if we adopt the rule that the thickness of the slab should be at least one-half the width of the rib, or perhaps permitting the reduction to one-third of the width of the rib on account of the reinforcement which will tend to prevent shearing, we need not pay any further attention to the tendency to shear in vertical planes along the rib. Expressing the above condition algebraically, we should say:

$$t > \tfrac{1}{3} b, \text{ or } b < 3\, t \ldots\ldots\ldots\ldots (19)$$

The summation (P') of the horizontal forces in the flange of the beam, is computed as follows:

It is assumed that the diminution of pressure from the upper fibers downward follows the usual law as already developed for simple beams. It is also assumed that the pressure on the fibers in any horizontal plane through the flange will also vary as the ordinates of a parabola. This is practically the equivalent of saying that the total pressure on the rectangle *mnvs* (see Fig. 56) is *two-thirds* of what it would be if *mnvs* were part of a simple beam, with width b' and effective depth d. We shall first compute the total pressure on the rectangle *mnop*, calling it *two-thirds* of the pressure on *mnop*, if it be a simple beam, and then subtract from it

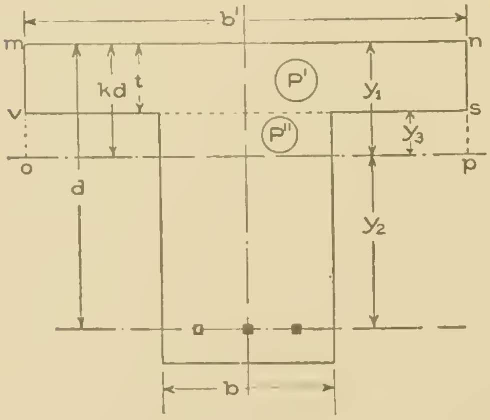


Fig. 56.

the pressure on $v s o p$, computed on the same basis. We may apply Equation 5 directly for the rectangle $m n o p$, and say that:

$$\text{Pressure on } m\,n\,o\,p = \frac{2}{3} \times \frac{7}{12} \times c'\,b'\,y_1.$$

For $v s o p$ we must apply Equation 4, since, for the fibers in the plane $v s$, q is not $\frac{2}{3}$, but is $\frac{2}{3}\,\frac{\mathrm{p\,s}}{\mathrm{p\,n}} = \frac{2}{3}\,\frac{y_3}{y_1}$. Substituting this value of q in Equation 4, we have:

$$\text{Pressure on } v\,s\,o\,p = \frac{2}{3} \times \frac{9}{8}\left(1 - \frac{2}{9}\,\frac{y_3}{y_1}\right)\frac{2}{3}\,\frac{y_3}{y_1}\,c'\,b'\,y_3\ ;$$

$$= \frac{1}{2}\left(1 - \frac{2}{9}\,\frac{y_3}{y_1}\right)\frac{y_3}{y_1}\,c'\,b'\,y_3\ ;$$

$$P' = c'\,b'\left\{\frac{7}{18}\,y_1 - \frac{1}{2}\left(1 - \frac{2}{9}\,\frac{y_3}{y_1}\right)\frac{y_3^2}{y_1}\right\} \dots\dots\dots\dots\dots\dots \mathbf{(20)}$$

The pressure (P'') on the rib between the flange and the neutral axis, is computed on the basis that the pressure on all fibers in any one horizontal plane is uniform (as in the case of simple beams), but that q is the same as above, $\frac{2}{3}\,\frac{y_3}{y_1}$. Applying Equation 4, we have:

$$P'' = \frac{9}{8}\left(1 - \frac{2}{9}\,\frac{y_3}{y_1}\right)\frac{2}{3}\,\frac{y_3}{y_1}\,c'\,b\,y_3\ ;$$

$$= \frac{3}{4}\,c'\,b\left(1 - \frac{2}{9}\,\frac{y_3}{y_1}\right)\frac{y_3^2}{y_1} \dots\dots\dots\dots\dots\dots\dots\dots\dots \mathbf{(21)}$$

It has already been shown in a previous section, that the allowable unit intensity of the shear, even for ultimate loads, equals

$$z \doteq \frac{c'}{6.928}.$$

Substituting this value in Equation 18, we have:

$$P' = S_h = 3b\,\frac{c'}{6.928}\,L = \frac{1}{2.309}\,b\,c'\,L.$$

For greater convenience in numerical calculation, and especially in view of the uncertainty of the value and the excessive margin allowed, this ratio is placed at the round value:

$$P' = \frac{4}{9}\,b\,c'\,L.$$

We may then place this value equal to the value of P' in Equation **20,** and solve for b':

$$P' = c'b' \left\{ \frac{7}{18} y_1 - \frac{1}{2}\left(1 - \frac{2}{9}\frac{y_3}{y_1}\right)\frac{y_3^2}{y_1} \right\} = \frac{4}{9} b c' L ;$$

$$b' = \frac{bL}{\frac{9}{4}\left\{ \frac{7}{18} y_1 - \frac{1}{2}\left(1 - \frac{2}{9}\frac{y_3}{y_1}\right)\frac{y_3^2}{y_1} \right\}} ;$$

$$= \frac{bL}{\frac{7}{8} y_1 - \frac{9}{8}\left(1 - \frac{2}{9}\frac{y_3}{y_1}\right)\frac{y_3^2}{y_1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

When the neutral axis is at or near the bottom of the slab, it is practically correct to say that:

$$b' = b\,L \div \frac{7}{8}\,y_1 \,.$$

If the beams are very deep, and the neutral axis is as far below the slab as the thickness of the slab, such an approximate value would be about 30 per cent too small.

Area of Steel. The required area of steel equals the total compression in the concrete, divided by s. Therefore,

$$A = \frac{P' + P''}{s} = \frac{4}{9}\frac{b\,c'}{s}L + \frac{3}{4}\frac{b\,c'}{s}\left(1 - \frac{2}{9}\frac{y_3}{y_1}\right)\frac{y_3^2}{y_1} \quad \ldots\ldots\ldots (23)$$

Moment of Section. The ultimate moment of the cross-section of a simple beam depends only on the dimensions of the cross-section. This would also be true of tee-beams, except for the fact that under some conditions the beam might fail by shearing under the flange; and the above theory provides for those conditions, by determining the pressure (P') as a function of the length of the beam (L). The determination of the precise points of application of the two forces P' and P'', is a very complicated mathematical problem. There is no material error in assuming that P' is applied at the middle of the

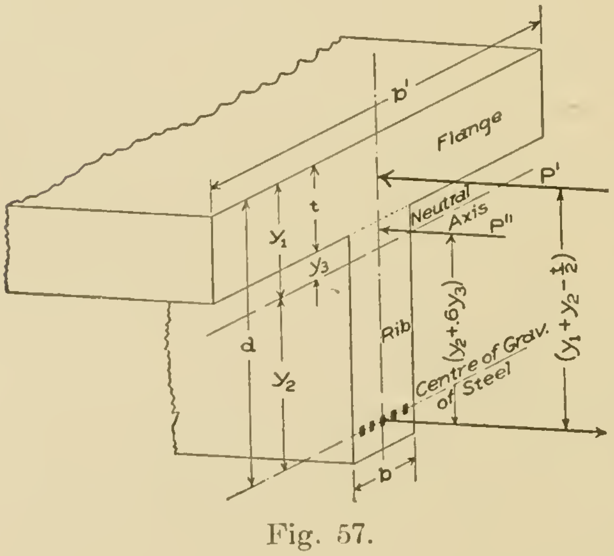


Fig. 57.

slab height, and that P'' is applied at $\frac{3}{5}$ of the height y_3. By taking moments about the center of gravity of the steel, we eliminate the steel tension from the equation, and have the equation:

$$M_o = P'\left(d - \frac{1}{2}t\right) + P''\left(y_2 + .6\, y_3\right);$$

$$= b\left\{\frac{4}{9}c'L\left(d - \frac{1}{2}t\right) + \frac{3}{4}c'\left(1 - \frac{2}{9}\frac{y_3}{y_1}\right)\frac{y_3^2}{y_1}\left(y_2 + .6y_3\right)\right\} \quad (24)$$

Design of Tee-Beams. Although Equations 22, 23, and 24 are the only equations which are essential to design tee-beams, the work is very tedious without the use of tables, since the equations involve unknown quantities which must be assumed first, and then tested whether the dimensions are mutually satisfactory. For any one grade of concrete, k has the same value as already figured for simple beams, and therefore for a beam of any assumed depth (say, d), kd, which in these calculations has been abbreviated to y_1, becomes known; $y_2 = (d - kd)$, and $y_3 = (y_1 - t)$. In any given numerical case, the thickness of the slab (t) is first computed on the basis of the floor load to be carried between beams spaced at a chosen distance apart.

We must then compute the weight of the live load on the panel whose area is the product of the span of the beam and the distance between beams. Adding to this an estimate for the dead weight of the floor, and multiplying the total load by 4, we have the ultimate load on one tee-beam. We then make an estimate of the *probable* required depth (d) of the beam. Knowing the quality of the concrete, we know the ratio k, which determines the position of the neutral axis; and we may then compute y_1, y_2, and y_3 as explained above. We also know the span L and the ultimate compressive strength of the concrete c'. Substituting all of these quantities in Equation 24, b is the only unknown quantity; and therefore we may solve the equation for b, which is the required width of the beam. We must apply two checks. In the first place, b must not be greater than three times the slab thickness (t). Also the breadth b', as computed from Equation 22, must not be greater than the distance between consecutive tee-beams.

Even though these two checks are satisfactory, it is quite possible that a recalculation should be made for a beam of greater or less depth, in order that the breadth b shall bear a more satisfactory proportion to the depth d. Of course, an increase in the depth d will result in a decrease in the computed width b, and *vice versa.*

Having satisfactorily settled on the depth d and the corresponding width b, we can determine the area of the steel from Equation **23.** All of the quantities on the right-hand side of Equation **23** are known, and the area may therefore be computed directly. As in the case of simple beams, the bars should be bent upward at an angle of 45°, as illustrated in Fig. 45. It will add considerably to the shearing strength in the horizontal plane immediately underneath the slab, if the bars which are bent upward are allowed to penetrate the slab, and are then bent so as to run horizontally for the remainder of their length within the slab. Of course this will occur only near the ends of the beams, where the shear immediately under the slab has its maximum value.

Numerical Example. Let us assume that a flooring for a building 20 feet wide is to be made of a 1:3:6 concrete floor-slab supported by concrete beams spaced 8 feet apart from center to center. We shall assume that the floor is to carry a live load of 150 pounds per square foot. An experienced man will know that a 5-inch slab will probably answer the purpose, and that this slab will weigh about 12 pounds per square foot per inch of thickness of the slab, or about 60 pounds per square foot. In this case, we shall obtain the ultimate loading by adopting the frequent practice of multiplying our live load (150) by 4, and our dead load (60) by 2, this giving 720 pounds per square foot ultimate load. With a span of 8 feet, and on a strip 1 foot wide, we have a total ultimate load of 720 × 8 = 5,760 pounds. We therefore have, for the ultimate moment:

$$M_o = \frac{W_o\, l}{8} = \frac{5{,}760 \times 96}{8} = 69{,}120 \text{ inch-pounds.}$$

Using Equation **13**, which is applicable in this case, we have:

$$397\, b\, d^2 = 69{,}120;$$

$$b\, d^2 = 174$$

But $b = 12$ inches; therefore $d^2 = 14.5$, and $d = 3.8$ inches. Therefore a 5-inch slab, with the bars 1 inch from the bottom, has a slight excess of thickness. The required area of steel equals $.0084\ b\, d = .0084 \times 12 \times 3.8 = .383$ square inches per foot of width.

This equals .032 square inch per inch, which will require $\frac{1}{2}$-inch bars, to be spaced 8 inches. The student should compare these results with those which may be derived directly from Table XI.

We have figured an ultimate load of 720 pounds per square foot for the floor-slab. In figuring the ultimate load for the tee-beam, we must add something for the dead weight of the beam itself. Of course this depends on the size of the beam, which is still an unknown quantity. It is usually found that the added amount of concrete in the beam underneath the slab is the equivalent of an added inch or two of thickness over the entire area of the slab. At 12 pounds per square foot per inch of thickness, this will add 12 or 15 pounds per square foot to the dead load. Multiplying this by 2 for factor of safety, we have, say, 30 pounds additional, and we may therefore say that the ultimate load per square foot for the beam shall be considered in this case 750 pounds rather than 720. Therefore, on the span of 20 feet, and with 8 feet between the beams, each beam must support an ultimate load of 8 × 20 × 750 = 120,000 pounds. Then,

$$M_o = \frac{W_o\, l}{8} = 120{,}000 \times 240 \div 8 = 3{,}600{,}000 \text{ inch-pounds.}$$

We must substitute this value of M_o in Equation **24**, and obtain the dimensions of the beam. This can be done only by assuming some value for the depth of the beam, and solving for b. We shall commence with the assumption that $d = 15$ inches. Using 1:3:6 concrete, $k = .395$; and kd therefore equals in this case 5.92 inches. This gives us the value $y_1 = 5.92$; and since $y_1 + y_2 = d$, then $y_2 = 9.08$; $y_3 = y_1 - t = 5.92 - 5.00 = 0.92$; $c' = 2{,}000$; L, which is the span in *feet*, $= 20$. This determines all the quantities in Equation **24** except the value b. Substituting these quantities in Equation **24**, we have:

$$b \left\{ \frac{4}{9} \times 2{,}000 \times 20\,(15 - 2.5) + \frac{3}{4} \times 2{,}000 \times \left(1 - \frac{2}{9}\,\frac{.92}{5.92}\right) \frac{.92^2}{5.92} \left(9.08 + .6 \times .92\right) \right\} = 3{,}600{,}000\,;$$

$$b \left\{ 222{,}222 + 1{,}500\,(1 - .034)\,.143 \times 9.63 \right\} = 3{,}600{,}000\,;$$

$$b\,(222{,}222 + 1{,}992) = 3{,}600{,}000\,;$$

$$b = \frac{3{,}600{,}000}{224{,}214} = 16.0 \text{ inches.}$$

But this trial value of b is greater than three times the thickness of the slab. It is also greater than the depth of the slab to the reinforcement, which shows that it is not an economical design, even if it fulfilled the other condition. We must therefore use a deeper beam. We shall accordingly make another trial with $d = 17$ inches. The student should work this out in detail, the calculation being very similar to that given above; and it will be found that b then = 13.6 inches. This being a suitable width for d = 17 inches—or a total depth of, say, 19 inches, or 14 inches under the slab—this combination of breadth and depth will be accepted.

The required area of the steel can now readily be found by a direct application of Equation **23**, since all the symbols on the right-hand side of the equation have now become known quantities. Making these substitutions, which the student should work out in detail, we find that the required area equals 4.55 square inches. This can be furnished by six $\frac{7}{8}$-inch square rods (area 4.59 square inches) or by eight $\frac{3}{4}$-inch square rods (area 4.50 square inches). Probably the eight $\frac{3}{4}$-inch rods would be the better choice, in spite of the slight deficiency in area, since it gives a better distribution of the metal, and furnishes a greater number of bars which may be turned up near the ends of the beam.

The student should work out still another combination of values for the above case, on the basis that d = 19 inches. He should find in this case that b will be 11.6 inches, but that the amount of steel required will be only 4.00 square inches. Although the amount of concrete will be very nearly the same in these last two solutions, the last method requires less steel, and is therefore more economical.

Shear. The theoretical computation of the shear of a tee-beam is a very complicated problem. Fortunately it is unnecessary to attempt to solve it exactly. The shearing resistance is certainly far greater in the case of a tee-beam than in the case of a plain beam of the same width and total depth and loaded with the same total load. Therefore, if the shearing strength is sufficient, according to the rule, for a plain beam, it is certainly sufficient for the tee-beam. In the above numerical case, the total *ultimate* load on the beam is 120,000 pounds. Therefore the maximum shear (V) at the end of the beam, is 60,000 pounds. With this grade of concrete, $d - x = .86\,d$. For this beam, d = 17 inches, and b = 13.6 inches. Substituting these values in Equation **15**, we have:

$$v = \frac{V}{b\,(d - x)} = \frac{60{,}000}{13.6 \times .86 \times 17} = 302 \text{ pounds per square inch.}$$

Although this is probably a very safe *ultimate* stress for direct shearing, it is 50 per cent in excess of the allowable direct ultimate tension due to the diagonal stresses; and therefore ample reinforcement must be provided. If only two of the $\frac{3}{4}$-inch bars are turned at an angle of 45° at the end, these two bars will have an area of 1.12 square inches, and will have an ultimate tensile strength (at the elastic limit of 55,000 pounds) of 61,600 pounds. This is more than the ultimate total vertical shear at the ends of the beam; and we may therefore consider that the beam is protected against this form of failure.

Tables for Computation of Tee-Beams. The above computation has purposely been worked out in detail in order thoroughly to explain every feature of the solution. If it were necessary to adopt identically the same method for the design of every tee-beam, the work would be very tedious. Fortunately the work may be very greatly simplified by solving Equations **22**, **23**, and **24** for some one grade of concrete and for various depths of beams. Such tables are illustrated in Tables XI to XIV inclusive. They are all worked out on the basis of the use of 1:3:6 concrete. Their use may be illustrated as follows:

Assume that a flooring having a span of 18 feet is to be supported by a 4-inch slab and by tee-beams spaced 6 feet apart, the working load being 150 pounds per square foot.

We shall compute, as before, an ultimate floor loading of 725 pounds per square foot, and the ultimate moment on one panel to be supported by one tee-beam of 2,349,000 inch-pounds. As a trial, we shall assume $d = 14$ as the proper depth. In Table XI, opposite $d = 14$, we find ultimate moment $= b\ (5{,}596 + 10{,}667\ L)$. Multiplying 10,667 by 20, and adding 5,596, we have 218,936. Dividing this into 2,349,000, we have $10\frac{3}{4}$ inches as the required width b. This being a proper proportion, it may be adopted. Substituting this value of b in the expression on the same line for "area of steel," we have:

Area of steel $= 10.75\ (.0108 + .0162 \times 20) = 3.60$ square inches of steel.

As a check, $b' = .227\, b\, l = .227 \times 10.75 \times 20 = 48.8$ inches. But, since the beams are spaced 6 feet (or 72 inches) apart, there is ample width of slab between each beam. The ultimate shear at the end of the beam is 39,150 pounds. Applying Equation **15**, we have in this case $(d - x) = .86\, d = 12.04$ inches. Then,

$$v = \frac{39{,}150}{10.75 \times 12.04} = 303 \text{ pounds per square inch.}$$

We may consider this as the diagonal tension in the end of the beam, which shows that it must be amply reinforced either by stirrups or by some of the reinforcing bars being bent up diagonally at the ends.

TABLE XI

Tee-Beams—1 : 3 : 6 Concrete—4-Inch Slabs

d	Ultimate Moment—M_0	Area of Steel—A	b'
11	$b(269 + 8{,}000L)$	$b(.0007 + .0162L)$	$.265\ bL$
12	$b(1289 + 8{,}889L)$	$b(.0030 + .0162L)$	$.248\ bL$
13	$b(3035 + 9{,}778L)$	$b(.0064 + .0162L)$	$.236\ bL$
14	$b(5596 + 10{,}667L)$	$b(.0108 + .0162L)$	$.227\ bL$
15	$b(8868 + 11{,}556L)$	$b(.0157 + .0162L)$	$.221\ bL$
16	$b(12993 + 12{,}444L)$	$b(.0213 + .0162L)$	$.215\ bL$
17	$b(17807 + 13{,}333L)$	$b(.0272 + .0162L)$	$.211\ bL$
18	$b(23502 + 14{,}222L)$	$b(.0335 + .0162L)$	$.207\ bL$
19	$b(29865 + 15{,}111L)$	$b(.0399 + .0162L)$	$.203\ bL$
20	$b(37133 + 16{,}000L)$	$b(.0467 + .0162L)$	$.201\ bL$
22	$b(53884 + 17{,}778L)$	$b(.0608 + .0162L)$	$.196\ bL$
24	$b(73755 + 19{,}556L)$	$b(.0754 + .0162L)$	$.193\ bL$

TABLE XII

Tee-Beams—1 : 3 : 6 Concrete—5-Inch Slabs

d	Ultimate Moment—M_0	Area of Steel—A	b'
13	$b(42 + 9{,}333L)$	$b(.0001 + .0162L)$	$.223\ bL$
14	$b(655 + 10{,}222L)$	$b(.0014 + .0162L)$	$.209\ bL$
15	$b(2{,}014 + 11{,}111L)$	$b(.0038 + .0162L)$	$.199\ bL$
16	$b(4{,}130 + 12{,}000L)$	$b(.0072 + .0162L)$	$.191\ bL$
17	$b(7{,}012 + 12{,}889L)$	$b(.0113 + .0162L)$	$.185\ bL$
18	$b(10{,}665 + 13{,}778L)$	$b(.0160 + .0162L)$	$.180\ bL$
19	$b(15{,}093 + 14{,}667L)$	$b(.0211 + .0162L)$	$.175\ bL$
20	$b(20{,}297 + 15{,}556L)$	$b(.0267 + .0162L)$	$.172\ bL$
22	$b(33{,}043 + 17{,}333L)$	$b(.0387 + .0162L)$	$.166\ bL$
24	$b(48{,}909 + 19{,}111L)$	$b(.0517 + .0162L)$	$.162\ bL$
26	$b(67{,}895 + 20{,}889L)$	$b(.0654 + .0162L)$	$.159\ bL$
28	$b(90{,}003 + 22{,}667L)$	$b(.0796 + .0162L)$	$.156\ bL$

TABLE XIII

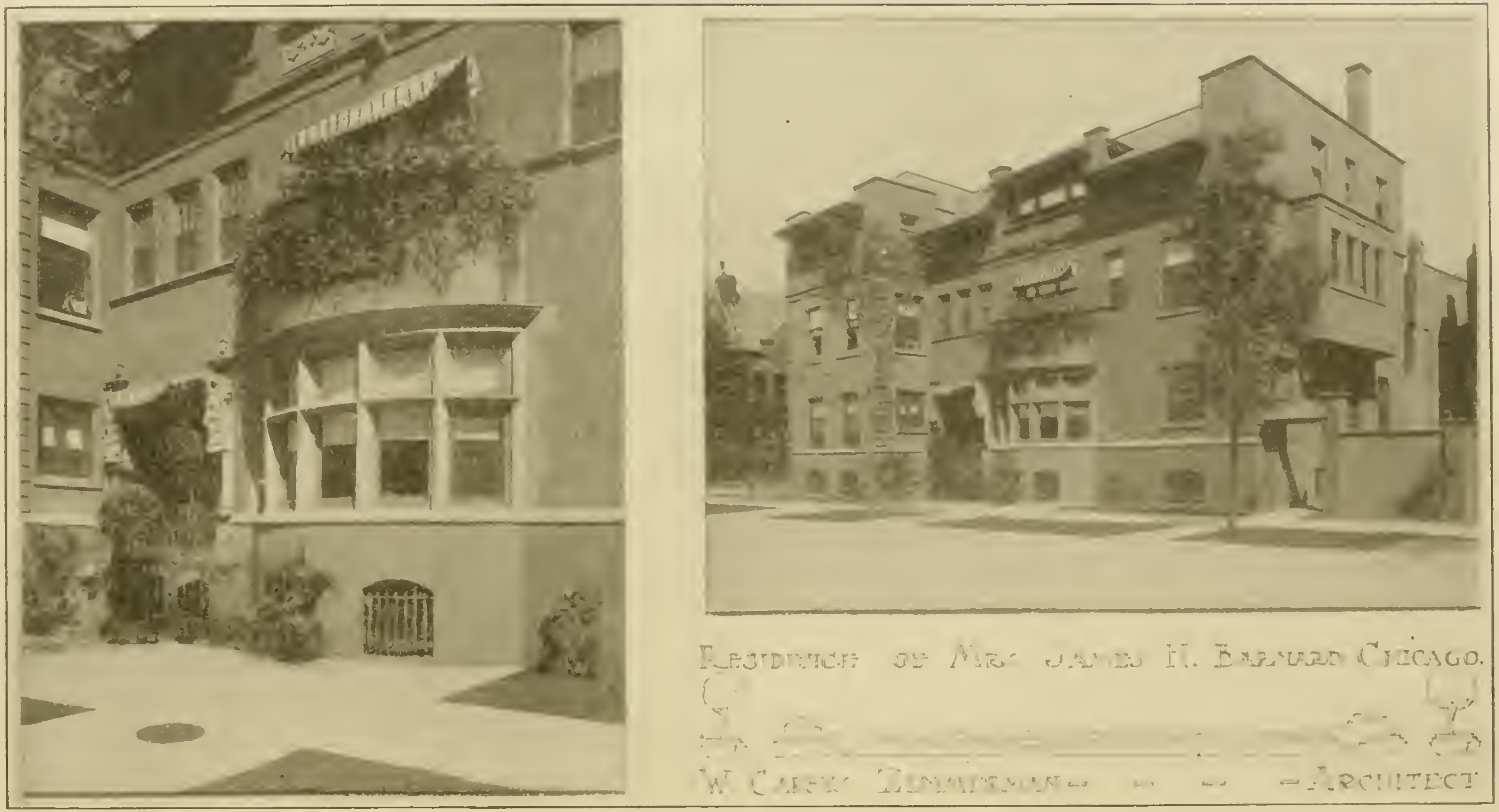
Tee-Beams—1 : 3 : 6 Concrete—6-Inch Slabs

d	Ultimate Moment—M_0	Area of Steel—A	b'
16	$b(237 + 11{,}556L)$	$b(.0004 + .0162L)$	$.181\ bL$
17	$b(1{,}195 + 12{,}444L)$	$b(.0020 + .0162L)$	$.173\ bL$
18	$b(2{,}900 + 13{,}333L)$	$b(.0046 + .0162L)$	$.166\ bL$
19	$b(5{,}362 + 14{,}222L)$	$b(.0079 + .0162L)$	$.160\ bL$
20	$b(8{,}590 + 15{,}111L)$	$b(.0118 + .0162L)$	$.156\ bL$
22	$b(17{,}358 + 16{,}889L)$	$b(.0206 + .0162L)$	$.148\ bL$
24	$b(29{,}228 + 18{,}667L)$	$b(.0320 + .0162L)$	$.143\ bL$
26	$b(44{,}212 + 20{,}444L)$	$b(.0139 + .0162L)$	$.139\ bL$
28	$b(62{,}313 + 22{,}222L)$	$b(.0567 + .0162L)$	$.136\ bL$
30	$b(83{,}536 + 24{,}000L)$	$b(.0701 + .0162L)$	$.134\ bL$
32	$b(107{,}882 + 25{,}778L)$	$b(.0841 + .0162L)$	$.132\ bL$

TABLE XIV

Tee-Beams—1:3:6 Concrete—7-Inch Slabs

d	Ultimate Moment—M_0	Area of Steel—A	b'
18	$b\,(28 + 12{,}889L)$	$b\,(.0000 + .0162L)$	$.161\ bL$
19	$b\,(592 + 13{,}778L)$	$b\,(.0009 + .0162L)$	$.153\ bL$
20	$b\,(1{,}895 + 14{,}667L)$	$b\,(.0027 + .0162L)$	$.147\ bL$
22	$b\,(6{,}756 + 16{,}444L)$	$b\,(.0086 + .0162L)$	$.138\ bL$
24	$b\,(14{,}672 + 18{,}222L)$	$b\,(.0164 + .0162L)$	$.131\ bL$
26	$b\,(25{,}676 + 20{,}000L)$	$b\,(.0266 + .0162L)$	$.127\ bL$
28	$b\,(39{,}783 + 21{,}778L)$	$b\,(.0373 + .0162L)$	$.123\ bL$
30	$b\,(57{,}003 + 23{,}556L)$	$b\,(.0492 + .0162L)$	$.120\ bL$
32	$b\,(77{,}342 + 25{,}333L)$	$b\,(.0618 + .0162L)$	$.118\ bL$
34	$b\,(100{,}802 + 27{,}111L)$	$b\,(.0750 + .0162L)$	$.116\ bL$
36	$b\,(127{,}383 + 28{,}889L)$	$b\,(.0888 + .0162L)$	$.114\ bL$


Residence of Mrs. James H. Barnard Chicago.
W. Carbys Zimmerman Architect

RESIDENCE OF MRS. JAMES H. BARNARD, CHICAGO, ILL.

W. Carbys Zimmerman, Architect, Chicago, Ill.

Located at Corner of Banks and Astor Sts. Erected in 1903 at a Cost of $32,500. Exterior of Red Pavers; Connecticut Brown Stone Trimmings. For Plans, See Pages 170 and 186.

STEAM AND HOT WATER FITTING

STEAM BOILERS AND CONNECTIONS

Small Cast-Iron Boilers. For small low-pressure steam heating jobs, boilers made up of very few sections are used. Two types are illustrated in Figs. 1 and 2. The ratings of such boilers range, as a rule, from about 200 square feet to 800 square feet. These figures and those following are intended to give merely a general idea of the capacities of boilers of various types. There is no hard and fast rule governing the matter, manufacturers varying greatly in their practice. The ratings mentioned are given in the number of square feet of direct radiation the boiler is rated to supply, with steam at from 3 to 5 pounds' pressure when the radiators are surrounded by air at 70° F.

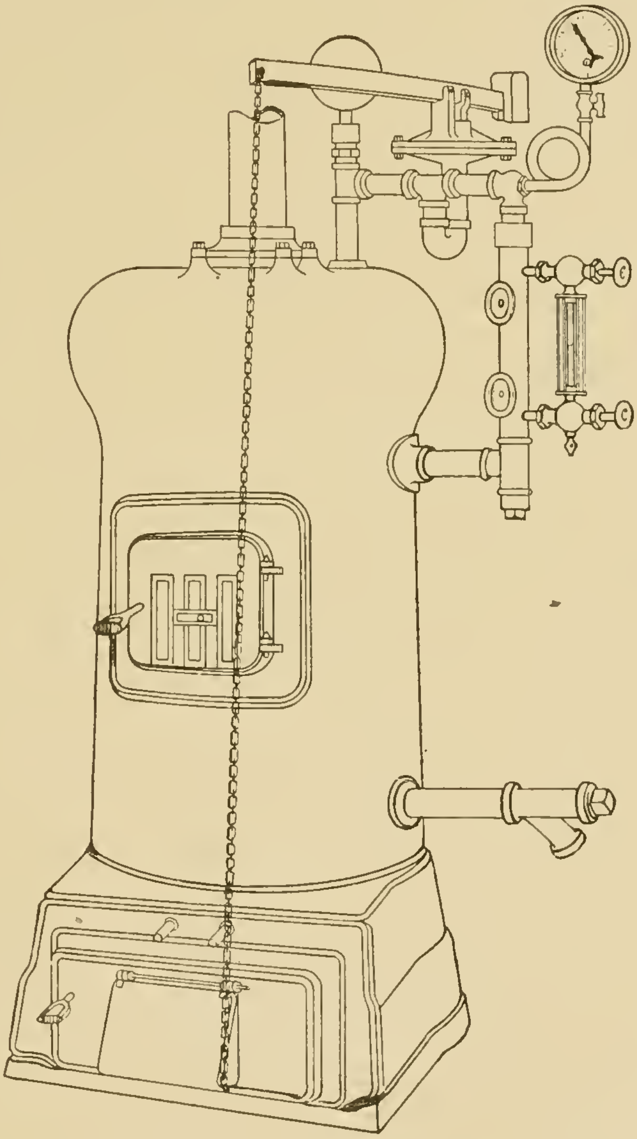


Fig. 1. Small Low-Pressure Steam Heating Boiler.

Boilers similar, in a general way, to the one illustrated in Fig. 3 are used for jobs somewhat larger than the boilers above described would be adapted to. These boilers have grates ranging generally from 18 inches to 36 inches diameter, and are rated from about 300 square feet to 1,600 square feet, or more.

The boilers above described have the disadvantage of not being capable of having their grate surface increased by adding sections, as may readily be done with boilers having vertical sections.

Cast-Iron Boilers with Vertical Sections. Boilers for jobs having anywhere from 500 to 5,000 square feet of surface, or more, are made up of vertical sections, as in Fig. 4, connected either by slip nipples or by drums and nipples with long screws and lock-nuts.

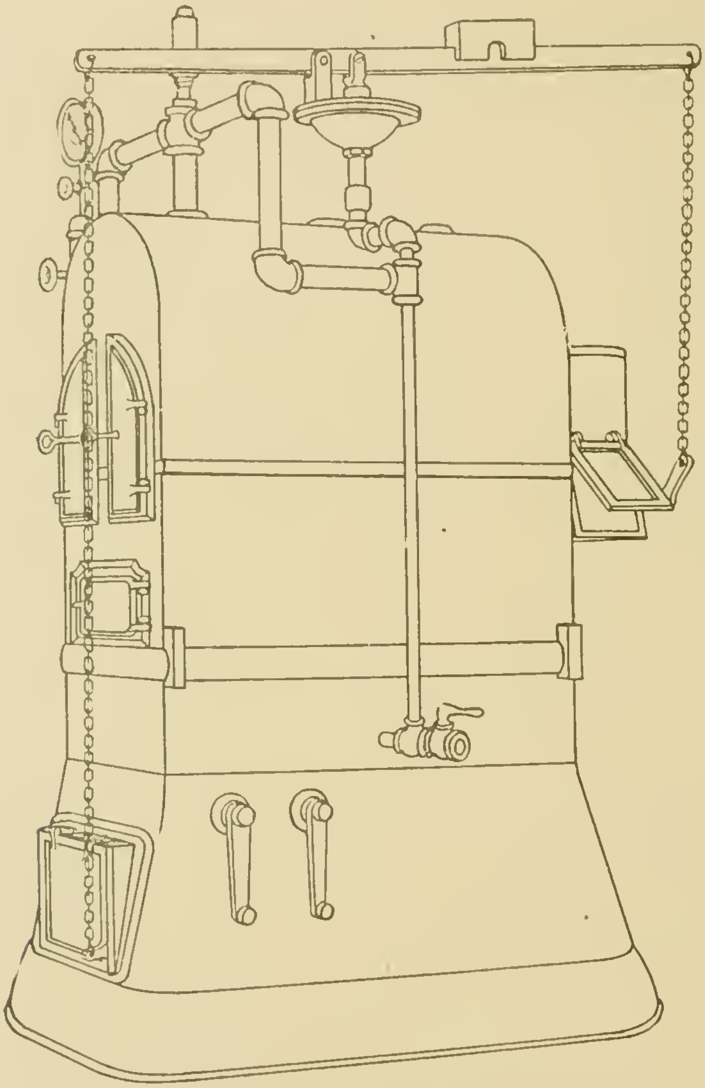


Fig. 2. Small Low-Pressure Steam Heating Boiler.

Very many slip-nipple boilers are now being manufactured, finding favor with fitters owing to the ease with which they can be erected.

The larger sizes of vertical sectional boilers are often made up of two sets of sections placed opposite each other, as shown in Fig. 5. Such boilers are rated up to 6,000 square feet and over.

Arrangement of Grates. Certain makers, in order to avoid making patterns for a boiler with a wide grate, secure the necessary grate surface by adding to the length. For ordinary low-pressure heating, the efficiency of any grate over 6 feet in length falls off very rapidly, owing to the difficulty of properly caring for the fire. Six feet should be considered about the limit for the length of a grate in a low-pressure boiler.

Not long ago few portable boilers with grates wider than 36 inches were manufactured. Now, boilers with 42-inch, 48-inch, and even wider grates, are common.

Selection of Boilers. It is well in selecting a boiler, to see that the proportion of heating surface to grate surface is not less than 16 to 1, and in large boilers not less than 20 to 1; that the fire-box is deep, so that ample coal may be put on to burn through the night; that the grate is not too long for convenient firing and cleaning; that there is ample steam space;

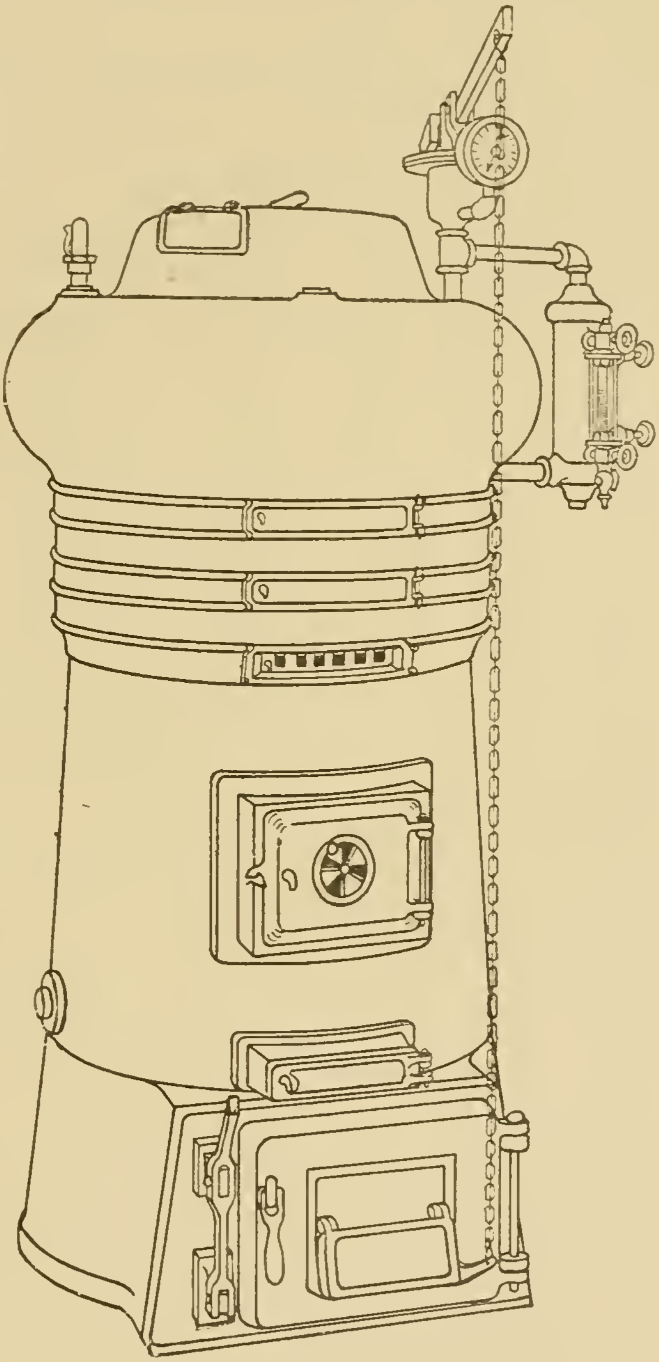


Fig. 3. Steam Heating Boiler.

and that the water line is not broken into too many small areas involving the likelihood that water will be lifted by rapid evaporation and wet steam result. See to it, also, that the ash-pit is deep, and that the grate is of a design that will permit convenient operation of the boiler.

On large jobs, it is better, as a rule, to use two boilers. One must remember that a plant must be designed for the coldest weather; and since the average temperature during the heating season is, in many Northern sections, not far from 40°, one of a pair of boilers will be sufficient under average conditions to do the work with economy; whereas a single, large boiler, during a good part of the heating season, would have to be run with drafts checked and under very unfavorable conditions as to economy. It is almost as poor economy to have too large a boiler as to have one too small, for, if run with the feed-door open or drafts closely checked, incomplete combustion takes place.

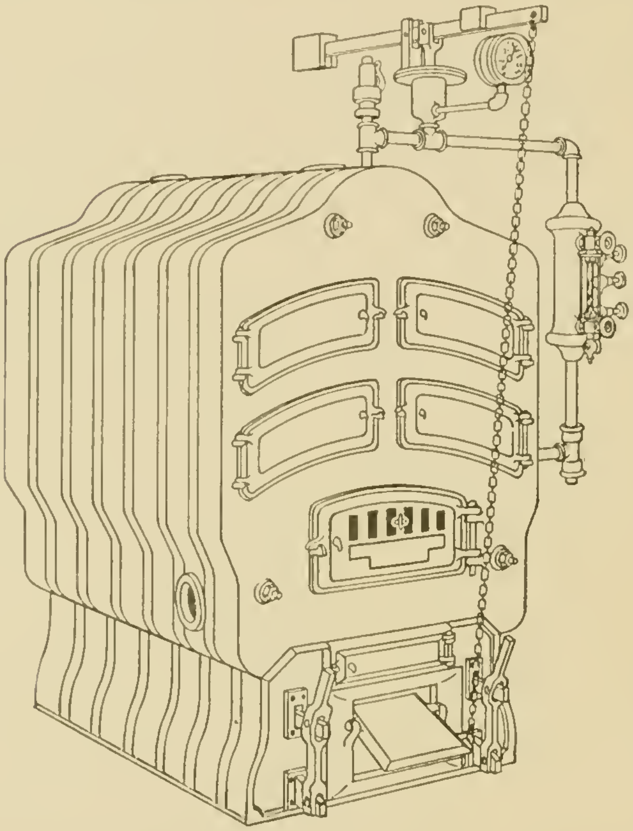
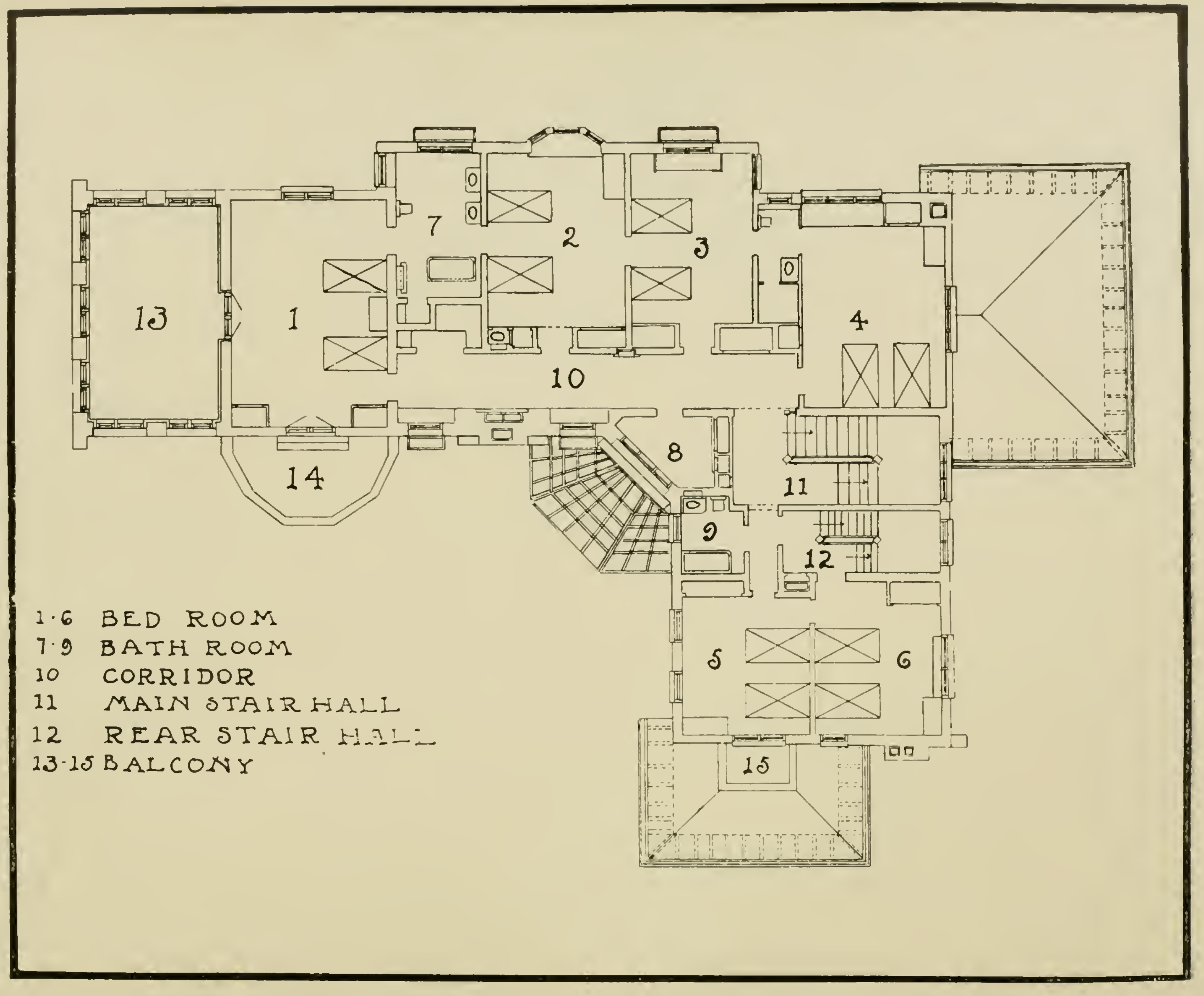


Fig. 4. Steam Heating Boiler with Vertical Sections.

Boilers for Soft Coal. Some boilers for burning soft coal are arranged with a perforated pipe or duct discharging heated air above the fire to make the combustion more complete and thus diminish the amount of smoke given off. This arrangement is of somewhat doubtful utility, since it is difficult to heat the air properly, and to regulate its admission.

It is necessary, for soft coal boilers, that the flues and smoke-pipe be larger than for hard coal heaters, in order to provide for the more rapid accumulation of soot. Soft coal boilers are also built on the



SECOND-STORY PLAN OF RESIDENCE FOR MR. FRED PABST ON OCONOMOWOC LAKE, WIS.

Fernekes & Cramer, Architects, Milwaukee, Wis.; Newton Engineering Co., Engineers.

For Exterior and First-Story Plan, See Page 122.

down-draft principle, the air being drawn down through the fire instead of passing upward in the usual manner.

Coke Boilers. Coke is a popular fuel in some parts of the country; and certain makers are putting out specially designed boilers for this service, having a very deep fire-box.

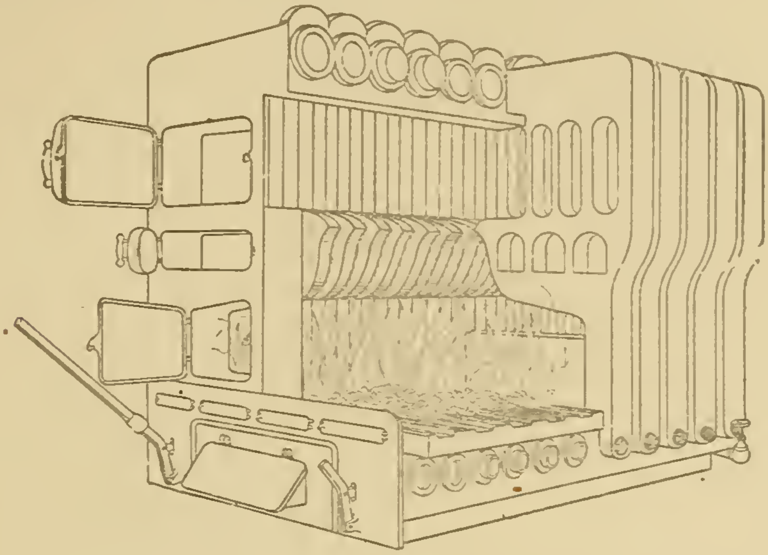


Fig. 5. Vertical Sectional Boiler.

Boiler Setting and Foundations. Brick setting of boilers, as in the case of furnaces, has been quite generally discarded, except in cases where the space around and above the boiler is used as a cen-

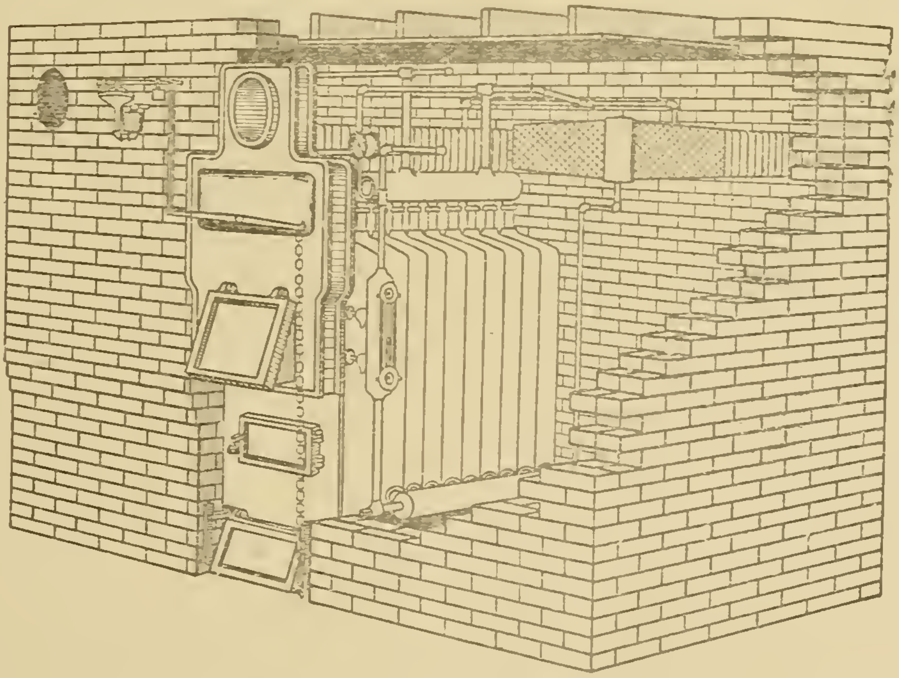


Fig. 6. Boiler in Brick Setting.

tral heating chamber for indirect systems, the radiators being placed above the heater (see Fig. 6). The pipes lead off as in furnace heating.

The ash-pits under most boilers are rather shallow; therefore

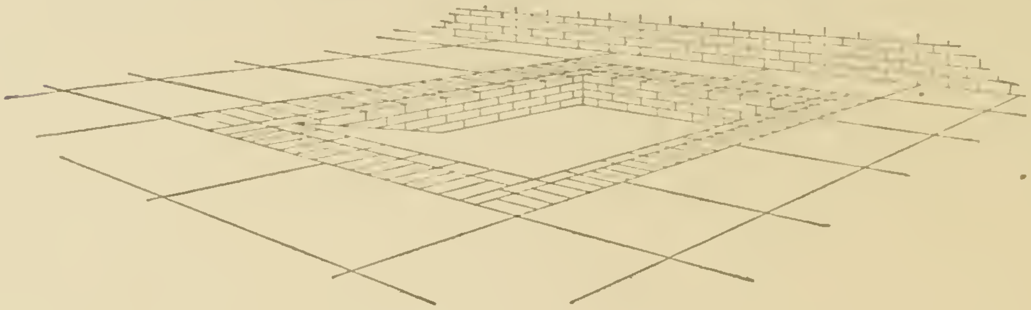


Fig. 7. Pit for Collection of Hot Ashes.

it is a good plan to excavate and build a pit not less than 4 to 6 inches below the floor, to give additional space for the collection of hot ashes, thus avoiding the burning-out of grates. Such pits should be built preferably of brick, and the bottom should be paved with bricks on edge, to prevent their being easily dislodged. Fig. 7 shows the general arrangement of an ash-pit built as described.

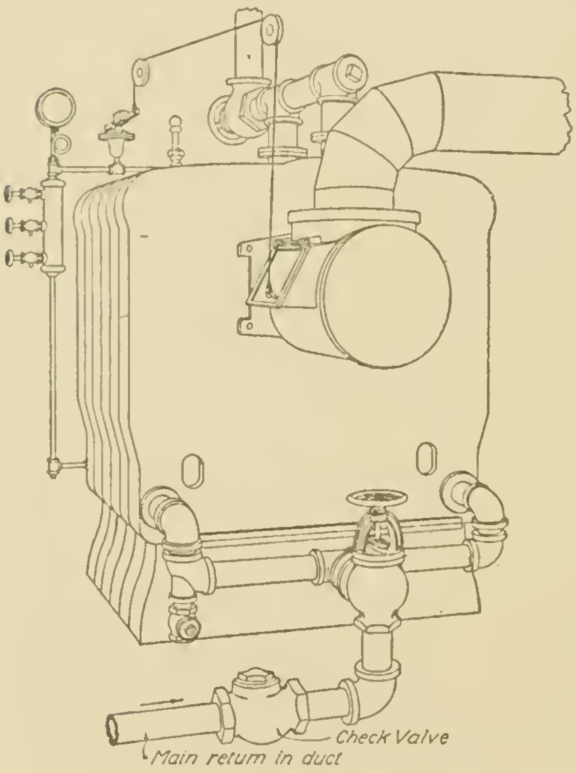


Fig. 8. Typical Arrangement of Return, Showing Check Valve.

Boiler Connections. Small jobs frequently have no stop valves at the boiler. In the case of larger ones, or where there are two boilers, valves in the supply mains must always be accompanied with check valves in the returns; otherwise, in case a stop valve in the main steam line is closed, the water will be backed out of the main returns at the boiler, by the pressure. Should the water partially leave the boiler in this manner and then suddenly return, the water coming in contact with the heated sections will crack them.

A stop valve should be placed between the boiler and the check valve in the return. A typical arrangement of return, etc., is shown in Fig. 8. It is convenient to have an independent drain connection from the returns to provide for drawing off the water in the system without emptying the water from the boiler. The latter, of course, has its independent blow-off cock. The water supply to the boiler should be controlled by a lock-shield valve or a cock that cannot be tampered with by any person not in charge. Boilers having eight sections or more, as a rule, have two or more steam outlets, thus reducing the likelihood of the boiler priming or making wet steam, since, with a single outlet, the velocity of steam through it may be so great that the water is picked up and carried into the piping system.

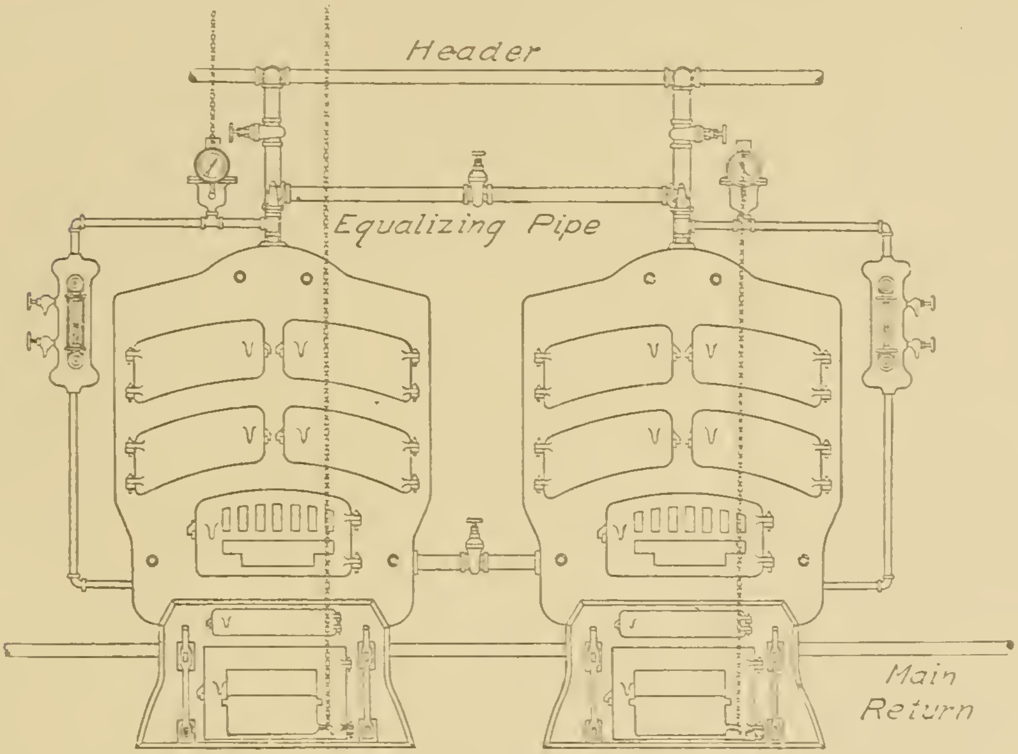


Fig. 9. Method of Connecting Two Boilers.

When two boilers are to be connected, especial care must be taken to make them maintain an even water line when working together. Fig. 9 shows a method of making these connections that is simple and effective. The valved connection between the two boilers, below the water, gives free communication between them, making them work as one and preventing a difference in the water level in the two boilers. The equalizing pipe is often omitted, the header being made about twice the diameter of the pipes leading to it from the boilers.

The returns are connected with the twin boilers practically as shown in Fig. 8, the check valve being placed between the stop valve of each boiler and the main return.

Boiler Fittings or Trimmings. It is important to have a reliable safety-valve, preferably one of the "pop" type specially designed for steam heating systems.

The damper regulators used are of the ordinary diaphragm pattern, and should be connected by chains with both the lower draft door below the grate, and with the cold-air check in the smoke connection.

The steam gauge with siphon, the water column, water gauge, gauge cocks, etc., require no special description.

Capacity of Boilers. Boiler capacities are commonly expressed in the number of square feet of direct radiating surface they will supply without undue forcing. Mains and risers should, of course, be added to the actual amount of surface in the radiators and coils. Even if the pipes are covered, a small allowance should be added to the combined surface of the radiators. Not less than 50 per cent, and preferably 60 per cent, must be added to indirect radiation, to reduce it to equivalent direct radiation; and not less than 25 to 30 per cent to direct-indirect radiation, to get its equivalent in direct surface. Another point to be kept in mind in selecting a boiler for heating rooms to be kept at different temperatures, is that more heat is given off per square foot of radiation in a room at 50°, for example, than in a room kept at 70°, the amount given off being approximately proportional to the difference in temperature between the steam and the air. With steam at, say, 220°, corresponding to a trifle over 2 pounds' pressure, the difference, in the case assumed, would be $220° - 50° = 170°$, and $220° - 70° = 150°$. That is, the actual amount of radiation in the rooms to be kept at 50° should be multiplied by $\frac{170}{150}$ to ascertain the amount of radiation in a 70° room that would give off the same amount of heat.

It is common practice to allow roughly for the loss of heat from uncovered mains, branches, and risers, by adding about 25 per cent to the actual direct radiating surface in radiators and coils.

Example. What should be the capacity of a boiler to supply steam to 1,000 square feet of direct radiation in a room to be kept at 70°, to 800 square feet of indirect radiation; and to 1,500 square feet of direct radiation, in rooms to be kept at 50° F.?

Direct radiation	1,000 sq. ft.
Equivalent in direct radiation of 800 sq. ft. of indirect = $800 \times 1\frac{1}{2}$ =	1,200 " "
Equivalent in direct radiation, in rooms at 70°, of 1,500 sq. ft. in rooms at 50° = $\frac{17}{15} \times 1{,}500$ =	1,700 " "
Total equivalent D. R. S. (direct radiating surface) exposed in 70° air =	3,900 sq. ft.
Add 25 per cent of actual surface to allow approximately for piping =	825 " "
Total equivalent D. R. S., or Boiler Rating =	4,725 sq. ft.

Grate Surface and Heating Capacity. It is advisable always to check the catalogue ratings of boilers as follows, when selecting one for a given service:

Suppose the Direct Radiating Surface, including piping, is 3,000 square feet. One square foot, it may be assumed, will give off about 250 heat units in one hour—a *heat unit* being the amount of heat necessary to raise the temperature of 1 pound of water 1 degree Fahrenheit. A pound of coal may safely be counted on to give off to the water in the boiler 8,000 heat units. Now, 3,000 sq. ft. × 250 heat units ÷ 8,000 heat units, gives the amount of coal burned per hour; and this, divided by the square feet of grate, gives the rate of combustion per square foot per hour. Suppose in this case, the grate has an area of 15 sq. ft.; then $\frac{3000 \times 250}{8000 \times 15} = 6.25$ pounds coal burned per square foot of grate surface per hour. This is not a high rate for boilers of this size, though for ordinary house-heating boilers the rate should not exceed 5 pounds; and for small heaters having 2 to 4 square feet of grate, the rate should be as low as 3 to 4 pounds per square foot of grate per hour. Otherwise, more frequent attention will be required than it is convenient to give to the operation of such small boilers. This is where depth of fire-box plays an important part, for, with a shallow fire, the coal quickly burns through, necessitating frequent firing.

Coal Consumption. For house-heating boilers a fair maximum rate of combustion is 5 pounds per square foot of grate per hour. In many residences it is the custom to bank the fire at night, when the rate will fall to, say, 1 pound. In cold weather, then, one square foot of grate would burn 5 pounds of coal for each of 16 hours, and 1 pound during each of the remaining 8 hours, a total of 80 + 8 = 88 pounds.

In many sections of the country, the average outside temperature during the heating season is about 40°; and since the heat required is proportional to the difference in temperature between indoors and outside, the average coal consumption would be only $\frac{70° - 40°}{70° - 0°} = \frac{3}{7}$ of the maximum in zero weather.

With a heating season of 200 days, the coal burned on one square foot of grate would be $200 \times \frac{3}{7} \times 88 = 7{,}600$ pounds in round numbers, corresponding to an average rate throughout the season of $\frac{7{,}600 \text{ pounds}}{200 \text{ days} \times 24 \text{ hrs.}} = 1.6$ pounds approximately.

A method of approximating the coal consumption for a given amount of radiating surface, designed to maintain a constant temperature in rooms of 70° day and night, would be to multiply the surface (which, for example, take at 1,000 square feet, including allowance for mains) by 250 heat units—the amount given off by a square foot per hour—and then multiply the product by $\frac{3}{7}$, as explained above, to allow for average conditions. This gives $1{,}000 \times 250 \times \frac{3}{7}$, which, divided by 8,000 heat units per pound of coal, gives the weight of coal required per hour; and this, multiplied by the hours per season, gives the total consumption.

Non-Conducting Coverings. It is customary to cover cast-iron sectional boilers with non-conducting material composed as a rule chiefly of asbestos or magnesia applied in a coating $1\frac{1}{2}$ to 2 inches thick, the exterior being finished hard and smooth.

Exposed basement piping in first-class work is covered with sectional covering $\frac{3}{4}$ inch to 1 inch thick, according to the character of the work.

The loss of heat through fairly good coverings, is not far from 20 per cent of the loss from a bare pipe, which, with low-pressure steam, is approximately 2 heat units per square foot per hour for each degree difference in temperature between the steam and the surrounding air.

STEAM RADIATORS AND COILS

Direct Radiators. The commonest forms of radiators to-day are the cast iron vertical loop varieties, types of which are shown in Figs. 2 and 13 in Part I (Heating and Ventilation). These are made up with slip-nipple or screw-nipple connections, the standard height being about 36 to 38 inches.

It is, of course, advisable to use radiators of standard height when possible, since they are cheaper than the lower radiators, which must be used when placed below window sills (see Fig. 10). Single-column radiators are more effective than those having a greater number of vertical loops, since in the latter the air flow is retarded and the outer loops cut off the radiant heat from the inner ones. Radiators with four or more columns are generally used where the length of the space in which they must be placed is limited.

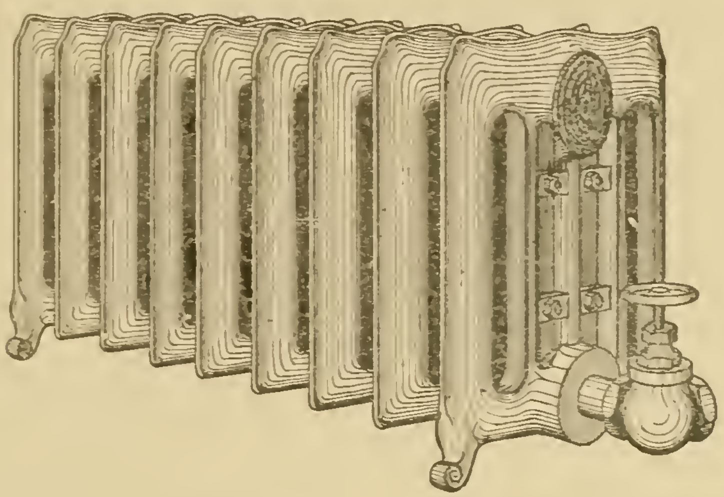


Fig. 10. Low Radiator to be Placed Below Window Sill.

Wall radiators (see Fig. 4, Part I, Heating and Ventilation) have become very popular because of their neat appearance and the small distance they project into the room. They are very effective heaters, and, although more expensive than certain other types of cast-iron radiators, less surface is required, which tends to offset the increased cost. These radiators are made up in such a variety of forms that they can be adapted to almost any location.

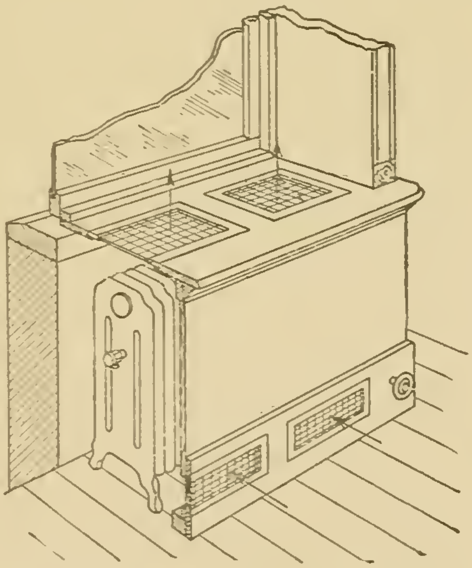


Fig. 11. Concealed Radiator with Register Face.

Concealed Radiators. A favorite method of concealing radiators is to place them below window-sills, with a grating or register face in front of and above them, as shown in Fig. 11. By this arrangement, the radiant heat is to a great extent cut off. The gratings must have ample area to permit the free circulation of air, and should have not less than 2 or $2\frac{1}{2}$ square inches of free area to each square foot of radiating surface, for inlets and outlets respectively. It is advisable to increase these allowances slightly when possible.

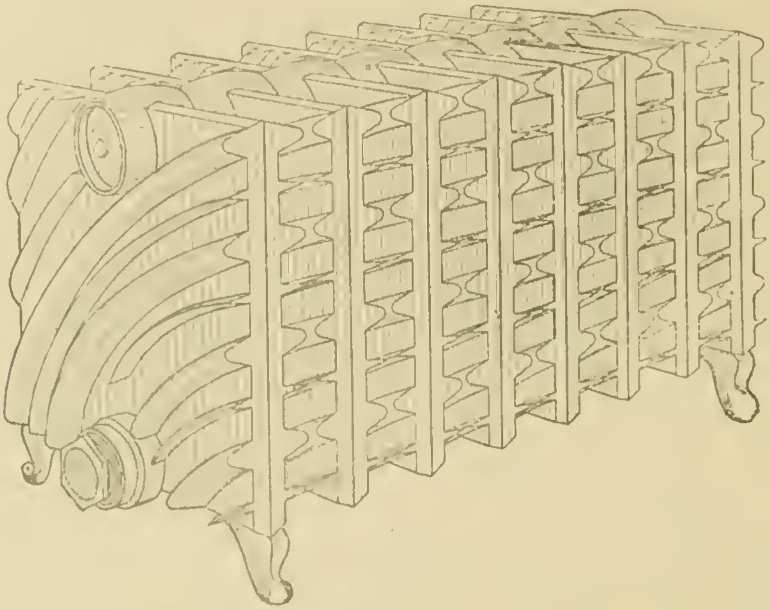


Fig. 12. Radiator for Use without Gratings.

The same rule applies to radiators placed below seats. A radiator designed specially for this purpose, for use without gratings, is shown in Fig. 12.

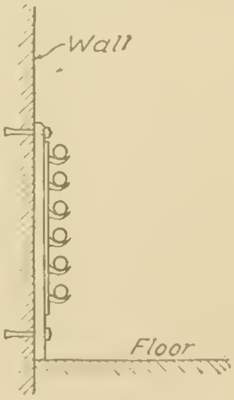


Fig. 13. Hook Plates.

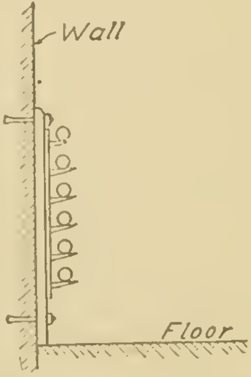


Fig. 14. Expansion Plates.

Wall Coils. An ordinary wall coil or manifold coil, made up generally of $1\frac{1}{4}$-inch pipe, with branch tees or manifolds, is illustrated in Fig. 39, Part I (Heating and Ventilation). The long runs of such coils rest on hook plates (Fig. 13); the short pipes near the corner, on expansion plates (Fig. 14), on which the pipes are free to move when the long pipes expand. Such coils are very effective when placed below the windows of a factory, in which class of buildings they find their widest application.

Miter Coils. Miter coils, as shown in Fig. 15, are used for overhead heating, the coils being suspended about 8 to 10 feet from the floor, and 3 to 4 feet from the walls. A good type of hanger is shown in Fig. 16. The same type of coil, when placed alongside a wall, is known in certain sections as a *harp* coil (see Fig. 17), and may be used where long runs must be made along a wall, but where it is impossible to install the type of coil shown in Fig. 39, Part I (Heating and Ventilation), owing to doorways or other obstructions. Two harp coils could be used along a wall, for example, avoiding a doorway; and the expansion of the pipes would be provided for by the short vertical lines.

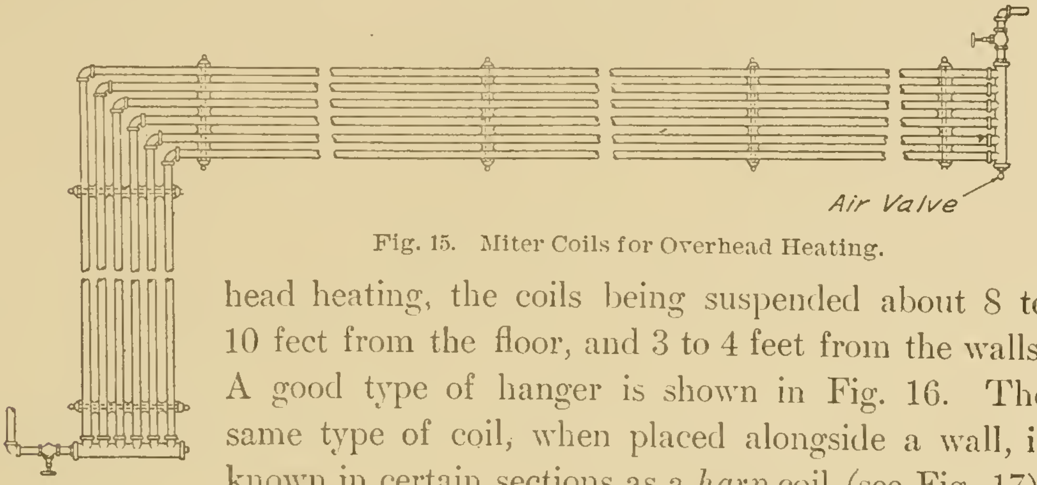


Fig. 15. Miter Coils for Overhead Heating.

Return-Bend Coils. Return-bend coils, known in some parts of the country as *trombone* coils, are shown in Fig. 40, Part I (Heating and Ventilation). These are suitable only for rather short runs, since the steam must pass through the several horizontal pipes successively, and, if the radiating surface is greater than the capacity of the upper line of pipe to supply it properly, the steam is condensed before reaching the lower lines. With the harp or other coils having headers or branch tees, sufficient steam can enter to fill all the pipes at once, passing through the parallel lines at the same time.

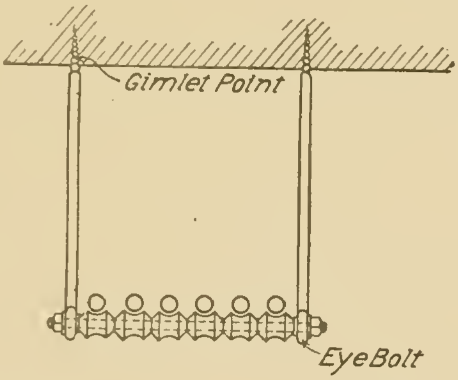


Fig. 16. An Approved Type of Hanger.

Direct-Indirect Radiators. A *direct-indirect* radiator is shown in Fig. 18. The air enters through a louvered or slatted wall opening with screen. Provision is made to shut this off and admit air simultaneously from the room, making the radiator essentially a direct radiator when the cold air is shut off. The best location for the cold-air opening is probably just below the sills, the wall boxes being less conspicuous in this position.

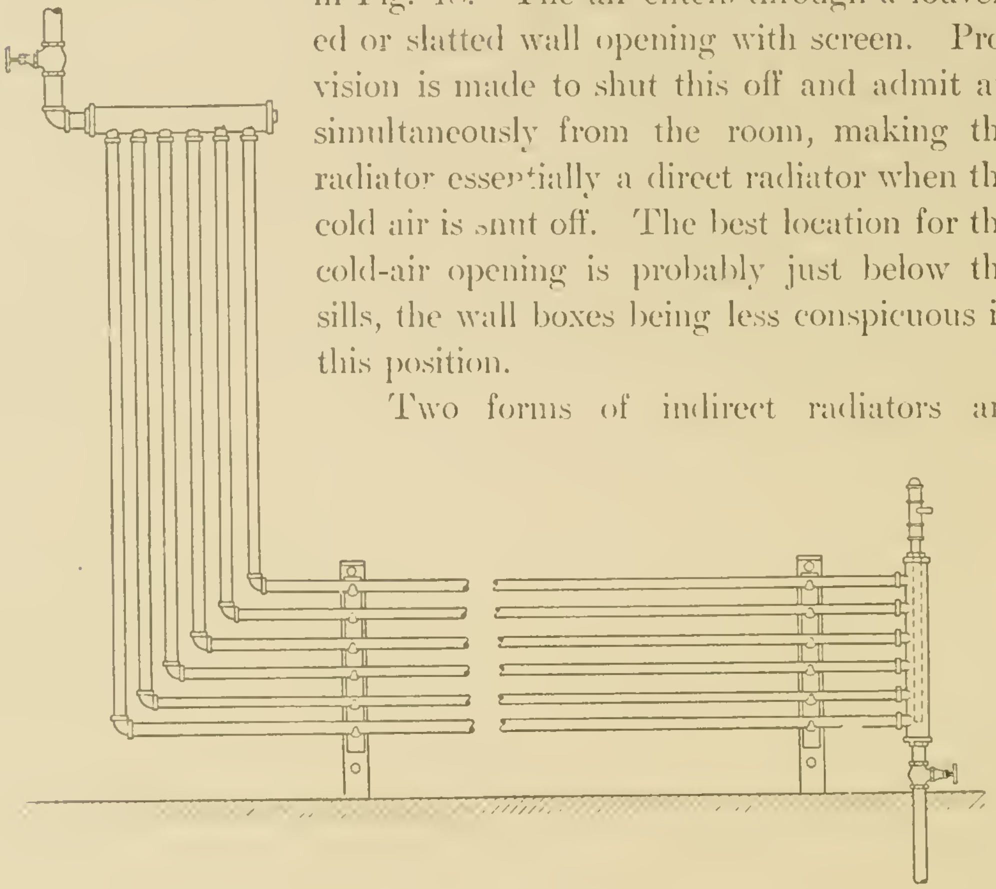


Fig. 17. Harp Coil.

Two forms of indirect radiators are shown in Fig. 7, Part I, and Fig. 3, Part II (Heating and Ventilation), the shallow sections being used largely for house heating, the deep ones for schoolhouse systems. The latter are provided with extra long nipples for spacing the sections about 4 inches on centers, to give a proper passage for a large volume of air.

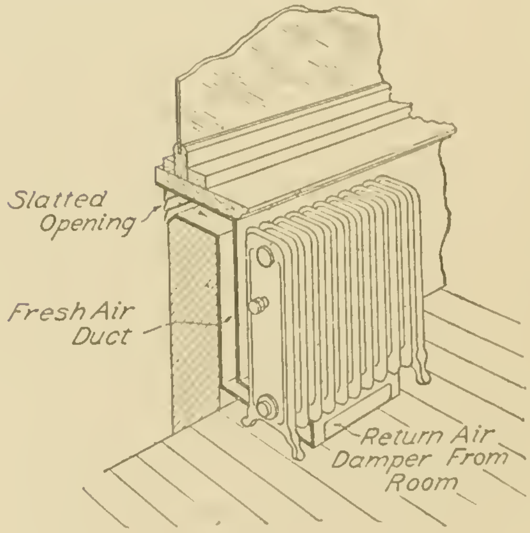


Fig. 18. Direct-Indirect Radiator.

Indirect Radiators. The indirect radiators are enclosed in galvanized-iron casings about 30 inches deep, giving a space of 6 or 8 inches above and below the radiators. The beams over the radiators are commonly covered with rough boards, to which tin or tin and asbestos is nailed, the casing being flanged at the top and screwed or nailed to these boards.

The casings should be made with corners of a type that will permit the ready removal of the sides in case of repairs being needed; and the bottom of the casing should be provided with a slide for inspection and cleaning. The larger sections, when used for schoolhouse heating, are arranged as shown in Fig. 19, with a mixing damper designed to cause a mingling of the warm and cold air in the flue, the volume discharged being but slightly reduced, with a decrease in temperature due to opening the damper to cold air. The space for the passage of air between the shallow sections containing about 10 square feet each, is about $\frac{1}{3}$ of a foot; the space between the sections of the deep pattern is not far from $\frac{1}{2}$ a foot when the sections are properly spaced.

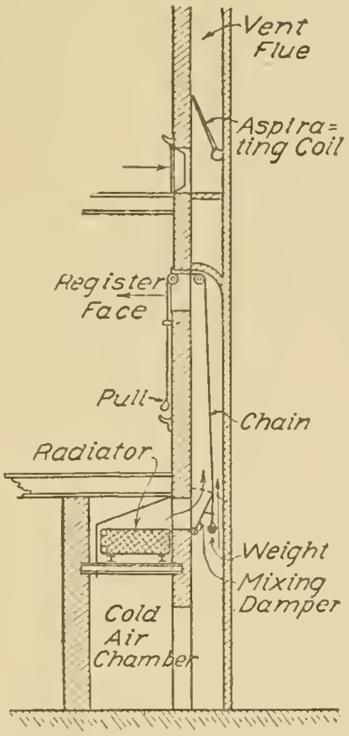


Fig. 19. Arrangement of Casings for Use in Connection with Indirect Radiators.

Heat Given Off by Steam Radiators. Of the heat emitted by direct radiators, approximately one-half is by radiation, the balance by convection or the contact of air. Since practically no heat is radiated from concealed radiators, it is very important that proper provision should be made for the passage of an adequate volume of air over the heating surface.

TABLE I

Heat Units Emitted from Radiators and Coils

Radiation per square foot of radiating surface per hour.—In rooms at 70° F. temperature.—With steam at 3 to 5 pounds' pressure.

Type of Radiator	Heat Units Emitted (Approximate)
Concealed cast-iron direct radiators	175–200
Ordinary cast-iron vertical-section radiators	250
Wall radiators	300
Pipe coils on walls	325
Pipe coils overhead (pipes side by side)	350
Ordinary cast-iron extended-surface indirect radiators (air admitted from outdoors)	400

Wall radiators and coils give off more heat under the same conditions than is emitted by ordinary vertical cast-iron radiators.

Much might be said regarding the efficiency of radiators due to their height, form, and arrangement. For the purposes of this course, however, only fair average values will be given, as set forth in Table I, a discussion of radiator tests, etc., being omitted to avoid unnecessary detail.

STEAM PIPING

Size of Main for Circuit System. Since the main of a circuit system, as described in Part I (Heating and Ventilation), must carry both steam and water of condensation, it should be made considerably larger in proportion to the surface supplied than mains which are dripped at intervals or which carry only the condensation from the main itself.

Sizes, ample for circuit mains of ordinary length, are indicated in the accompanying table:

TABLE II

Sizes of Circuit Mains

Diameter of Circuit Main	Direct Radiating Surface
2 inches	200 sq. ft.
2½ "	350 " "
3 "	600 " "
3½ "	900 " "
4 "	1,200 " "
4½ "	1,700 " "
5 "	2,100 " "
6 "	3,000 " "

Dry Return System. In many cases it is desirable to run the supply and return mains overhead. Such systems contain less water than wet return systems, and are therefore more susceptible to changes in the fire, because of the smaller quantity of water in the apparatus. The return mains must be made larger than when they are placed below the water line, since they are filled with steam, except the space occupied by the return water running along the bottom. The pipes should have a greater pitch than wet returns.

With dry returns, if certain supply risers are of inadequate size, steam is apt to back up into the radiator through the dry returns and to cause a holding-back of the water in the radiators. To prevent this, check valves are sometimes introduced in the branch returns. If the piping is properly proportioned, however, this is unnecessary. Siphon drips are frequently used, as explained in Part I (Heating and Ventilation).

Wet Return Systems. This system, illustrated in Fig. 20, provides for water sealing all returns and drips, and avoids the backing-up action mentioned above. Suppose, for example, the pressure in one of the vertical returns is ½ pound less than in the others; then, since a column of water 2.3 feet high corresponds to 1 pound pressure, the water will back up this particular return about 1.15 feet higher than in the others and thus equalize the difference in pressure. Where the mains must be long, the wet return system affords the opportunity to rise and drip the supply main as often as necessary; whereas, with the dry return system, the main and return have a gradual pitch from start to finish. This often brings the return so low as to interfere with head room. With the wet return system the return may be dropped below the floor line at doorways without interfering with the circulation. The sizes of wet returns may be made considerably smaller than dry returns for a given radiating surface, as shown in Table III.

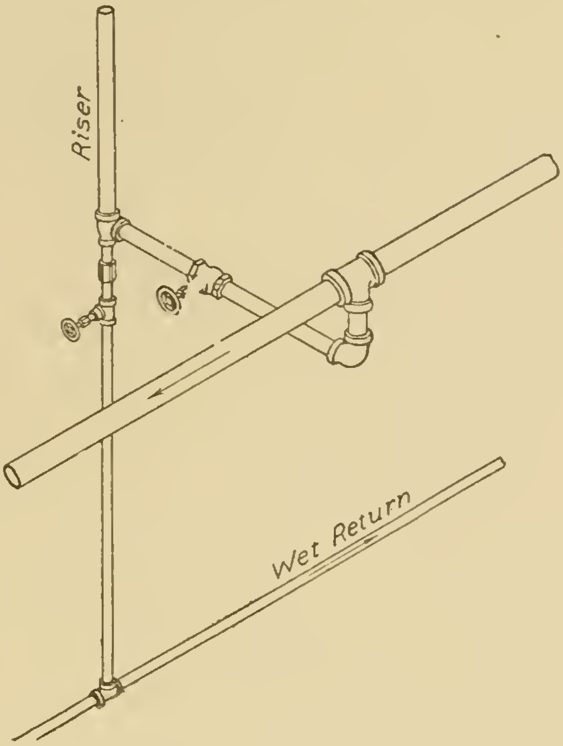


Fig. 20. Wet Return System.

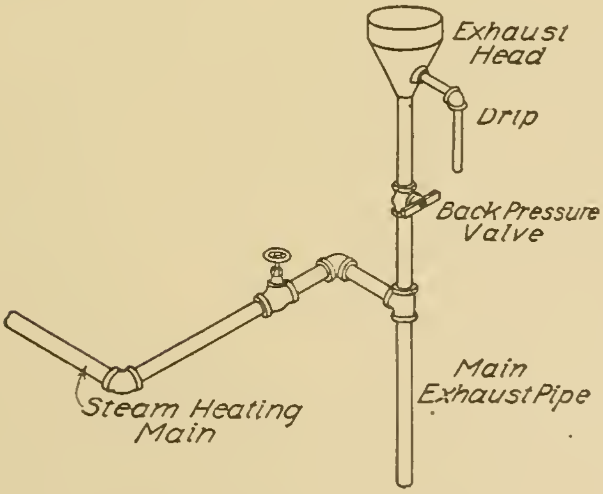


Fig. 21. Overhead Feed System.

Overhead Feed System. The overhead feed system (see Fig. 21) is most commonly used in connection with exhaust steam plants, since in such systems the exhaust pipe from the engines must be carried to the roof, and the steam supply to the building may conveniently be taken from a tee near the upper end of this pipe. The main should be pitched down, and outlets taken from the bottom, to drain the condensation through the risers (see Fig. 22). With this system the water of condensation always flows in the same direction as the steam; hence the horizontal pipes and the risers may be made somewhat smaller than in up-feed systems.

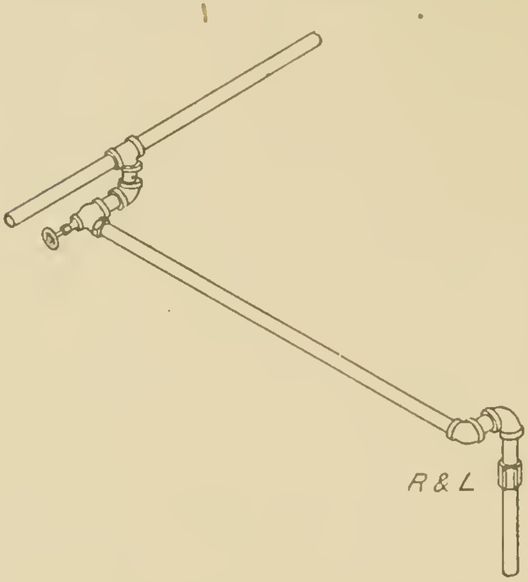


Fig. 22. Outlet Taken from Bottom of Main.

This system has the advantage of placing the big pipes in the attic, where their heating effect is less objectionable than in the basement. As the pipes gradually decrease in size from top to bottom, this gives small pipes on the lower floors, which in modern buildings generally contain a few large rooms and little space for concealing pipes. It is frequently advisable to combine with this system the up-feed method of heating the first floor, which is generally high-studded and requires a large amount of radiation. Relieving the down-feed system of this load means smaller risers throughout the building, which, in the modern sky-scraper, results in a saving that more than offsets the cost of the separate up-feed system for the lower floor. Another reason why it is advisable to put the lower floor on a separate system, is that the steam is dry, whereas the steam from an overhead system becomes pretty wet from condensation by the time it reaches the lower floor.

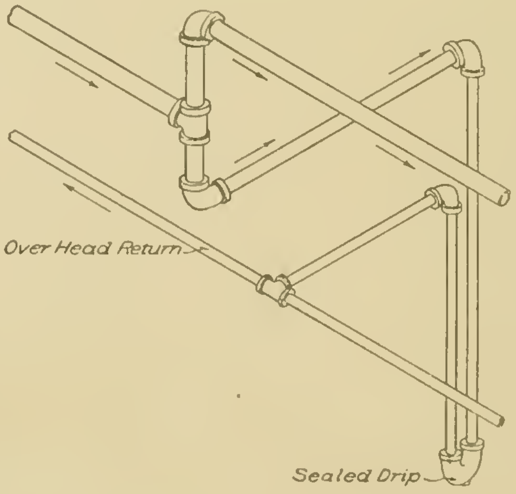


Fig. 23. Siphon Trap.

One-Pipe System. The one-pipe up-feed system is most commonly used in connection with relatively small heating plants. It has the advantage of simplicity, there being but a single valve to operate. In tall buildings with the up-feed system, the risers must be objectionably large to provide for the passage of steam up, and water of condensation down, the same pipe. With the overhead system, the risers may be made considerably smaller, since the water is not hindered in its passage by a flow of steam in the opposite direction. With this one-pipe system, the radiator connections should be short and pitched downward toward the risers to avoid pockets. When used in high buildings with the overhead system, the lower portion of the risers must be liberally proportioned, otherwise the steam will become too wet.

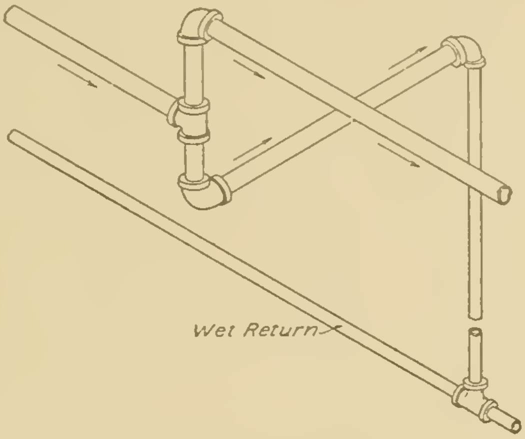


Fig. 24. Arrangement to Rise and Drip in Mains at Intervals.

The Two-Pipe System. This system is commonly used where the radiator connections must be long and where it would be impossible to secure a proper pitch to insure good drainage with one-pipe radiator connections. Coils are nearly always made up with two-pipe connections. In high buildings, where a large amount of radiation must be carried by each riser, they may be made smaller if two-pipe connections are made with the radiators. This is often a decided advantage, especially if the risers are to be concealed.

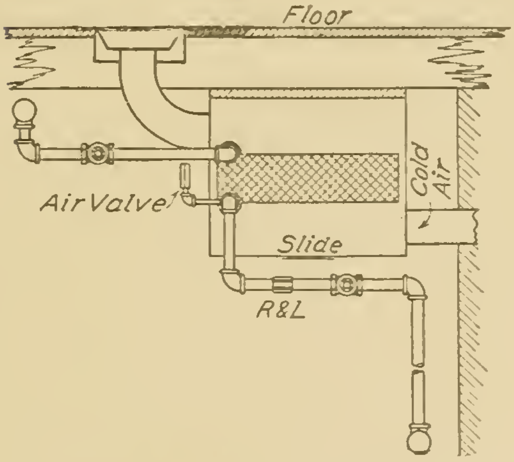


Fig. 25. Arrangement for Draining with Indirect System.

Draining Mains and Risers. With long mains, it frequently is the case that if given a continuous pitch they would be too low at the extreme ends; and it is therefore customary to rise and drip at intervals, as shown in Figs. 23 and 24.

The *siphon trap* (Fig. 23) prevents a greater pressure being introduced along the overhead return than occurs at the extreme end, since any excess in pressure at an intermediate point merely forces down the water in the inlet leg of the siphon trap to a point where the difference in pressure in the two mains is equalized by the higher level of water maintained in the outlet pipe of the syphon trap.

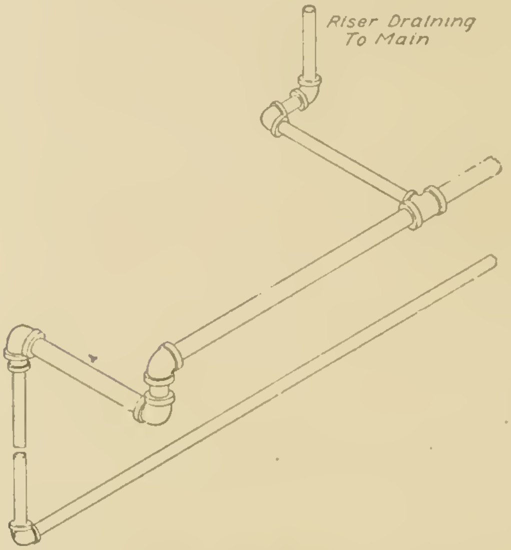


Fig. 26. Risers Drained to Main and Main Drained at End.

With indirect systems, the mains are frequently drained through the benches or stacks of radiators, the connections being taken from the bottom of the main. It is assumed that all the indirects will not be shut off at the same time (see Fig. 25).

Mains and risers are commonly drained as shown in Fig. 20, connections being taken from the bottom of the main and the heel of the riser. Risers are not infrequently drained to the main, which in turn is drained at the end (see Fig. 26). This arrangement requires less fitting than when the risers are relieved at the base, as shown in Fig. 20. If the mains are long, they should be dripped at intervals of 50 to 75 feet.

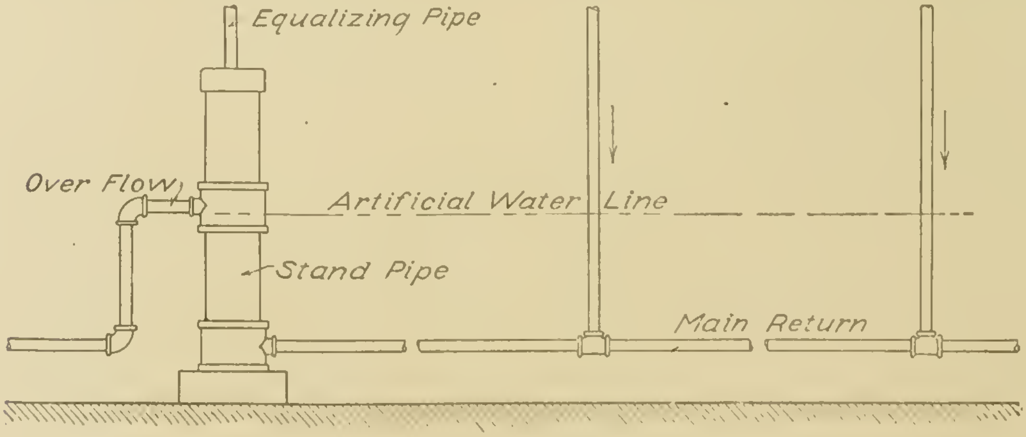
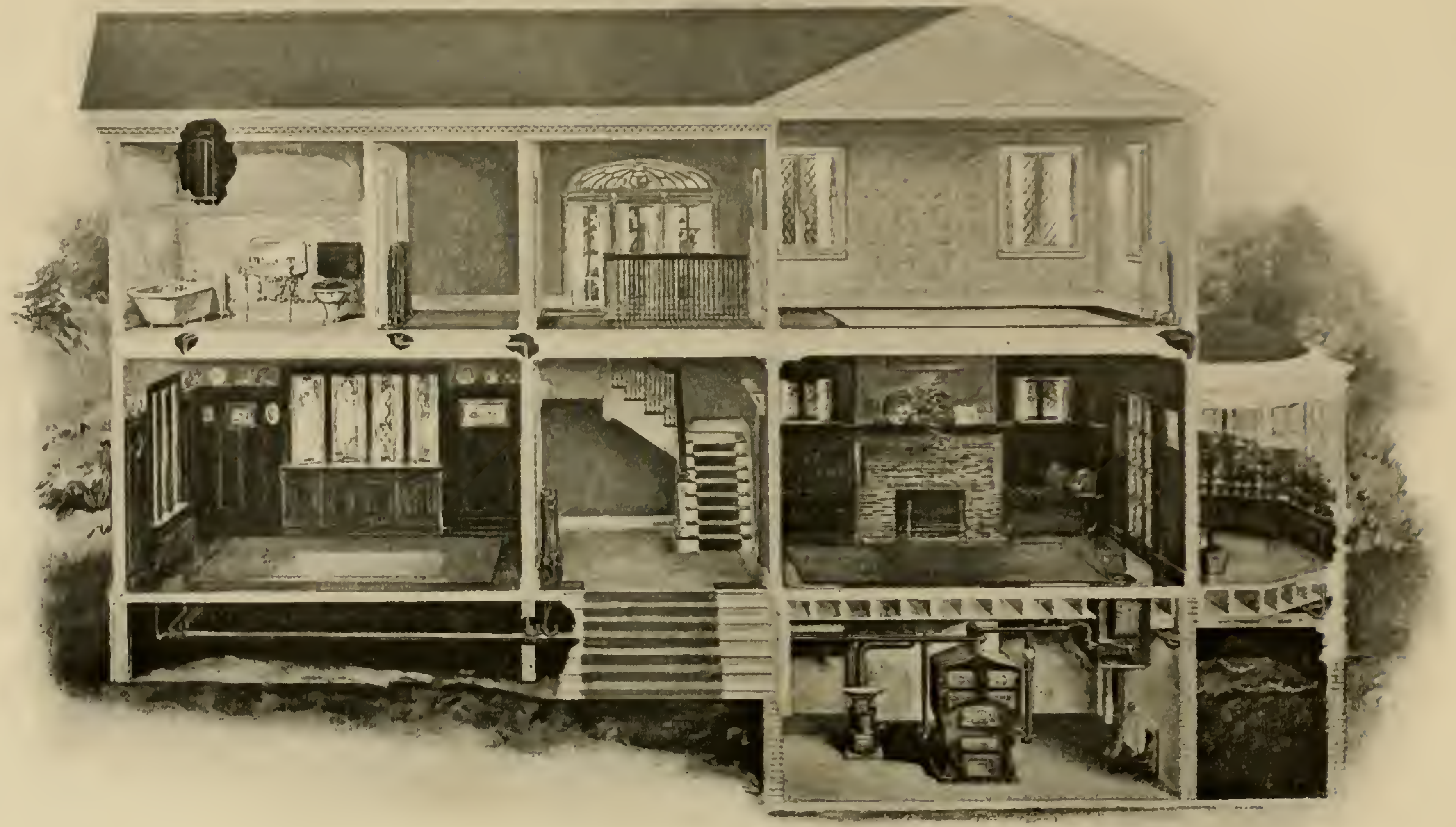


Fig. 27. Showing Artificial Water Line.

Overhead-feed mains on a down-feed system are nearly always dripped from the bottom to the various risers, as previously stated.

Artificial Water Line. It is sometimes necessary, when a boiler



TRANSVERSE SECTIONAL VIEW OF COLONIAL MODEL HOUSE, SHOWING INSTALLATION OF HEATING PLANT.

Exhibited by the American Radiator Company at the St. Louis World's Fair, in 1904.

is set very low with reference to the returns, and it is desired to use a wet return system, to seal the relief pipes by means of an artificial water line established as shown in Fig. 27. The equalizing pipe is to be connected with a steam main.

When the discharge from the system leads to an open return, a trap must be used. One of the type shown in Fig. 28, arranged with an equalizing pipe and set at the proper level, will hold the water line in the system, no stand-pipe being required.

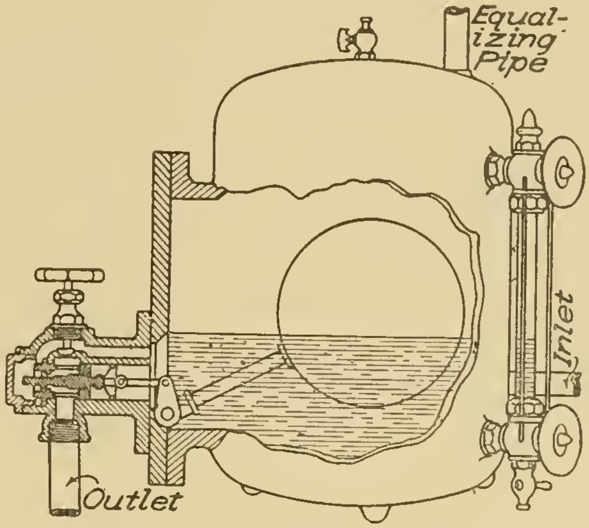


Fig. 28. Water Line Trap with Equalizing Pipe.

Pipe Sizes.—Mains. The capacities of pipes to supply heating surface increase more rapidly than their sectional areas; that is, a 6-inch pipe, with about four times the area of a 3-inch pipe, will supply nearly six times as much surface.

Table III shows the amounts of radiating surface in gravity-return systems which main pipes 100 feet long, of different diameters, may be safely counted on to supply with low-pressure steam (say, 3 to 5 lbs.).

In case the radiating surface is located some distance above the water line in the boiler, the carrying capacity of the pipes may be increased as much as 50 per cent, owing to the greater drop in pressure that may be allowed without interfering with the return of water to the boiler.

Mains are frequently made much larger than necessary, simply because the fact has been overlooked that the radiators are located well above the boiler, and that a drop in pressure between the boiler and the end of the main of $\frac{1}{4}$ lb., or even more, would be permissible.

The greater the drop in pressure allowed the smaller may be the pipe for a given capacity.

Pipe Sizes.—One-Pipe Risers. Riser capacities are given in Table IV.

TABLE III

Capacity of Supply Mains, Gravity Return System, and Size of Dry and Wet Returns

Mains 100 ft. long.—Steam at low pressure (3 to 5 lbs.).

DIAMETER OF SUPPLY PIPE	CAPACITY IN DIRECT RADIATING SURFACE	DIAMETER OF DRY RETURN	DIAMETER OF WET RETURN
1 inch	55 sq. ft.	¾ inch	¾ inch
1¼ inches	115 “ “	1 “	1 “
1½ “	175 “ “	1¼ inches	1¼ inches
2 “	325 “ “	1½ “	1¼ “
2½ “	570 “ “	2 “	1½ “
3 “	1,000 “ “	2½ “	2 “
3½ “	1,480 “ “	3 “	2½ “
4 “	2,000 “ “	3 “	2½ “
4½ “	2,770 “ “	3 “	2½ “
5 “	3,500 “ “	3½-4 “	3 “
6 “	5,700 “ “	4-5 “	3½-4 “
7 “	8,800 “ “	4-5 “	4 “
8 “	12,000 “ “	4-5 “	4 “
10 “	20,000 “ “	5-6 “	4 “
12 “	33,000 “ “	5-6 “	4-5 “

For lengths greater than 100 ft. and for same drop in pressure as for 100 ft., multiply the above figures by 0.8 for 150 ft.; 0.7 for 200 ft.; 0.6 for 300 ft.; 0.5 for 400 ft.; 0.4 for 600 ft.; and 0.3 for 1,000 ft. When the pressure at the supply end of the pipe can be increased for long runs so that the drop in pressure for each 100 ft. can be the same, then the figures in the table can be used for long runs.

TABLE IV

Capacities of One-Pipe Risers

SIZE OF PIPE	CAPACITY, UP-FEED	CAPACITY, DOWN-FEED
1 inch	30 sq. ft.	60 sq. ft.
1¼ inches	60 “ “	110 “ “
1½ “	120 “ “	160 “ “
2 “	200 “ “	260 “ “
2½ “	300 “ “	400 “ “
3 “	450 “ “	600 “ “
3½ “	620 “ “	800 “ “
4 “	800 “ “	1,000 “ “

The capacities of the 1-inch and 1¼-inch pipes for up-feed are somewhat greater than those stated; but they are given as above, since these figures correspond closely to standard radiator tapping, and it is advisable to make the pipes of the same size as the tapped openings.

In high buildings with the down-feed system, the lower half of the risers should be based on not much more than half the capacities stated in the right-hand column, in order that the pipes may be of ample size to carry off the great amount of condensation from the radiators above, without making the steam too wet for use in the radiators below. The pipe to the lowest radiator connection should be not less than 2-inch.

Pipe Sizes.—Two-Pipe Risers. With the two-pipe system, the capacity of the risers is of course, considerably greater than with the one-pipe system, since the condensation is carried off through a separate system of returns.

Table V gives the approximate capacities of risers for the two-pipe system.

TABLE V

Capacities of Two-Pipe Risers

Size, Supply Riser	Capacity, Up-Feed System	Capacity, Down-Feed System	Size, Return Riser
1 inch	50 sq. ft.	55 sq. ft.	¾ inch
1¼ inches	100 " "	115 " "	1 "
1½ "	150 " "	175 " "	1 -1¼ inches
2 "	270 " "	325 " "	1 -1¼ "
2½ "	470 " "	570 " "	1¼-1½ "
3 "	840 " "	1,000 " "	1¼-1½ "
3½ "	1,200 " "	1,480 " "	1½-2 "
4 "	1,690 " "	2,000 " "	1½-2 "

In buildings over six stories high, with the up-feed system, use 10 per cent less surface than stated in the third column, to allow for the increased length and condensation.

Pipe Sizes, Indirect. Supply connections with indirect radiators must be larger for a given surface than for direct radiators. The following table gives ample sizes when the radiators are but little above the water line of the boiler. When this distance is considerable, the pipes may be safely rated to supply one-third more surface; for a greater drop in pressure may be allowed between the

TABLE VI

Sizes of Supply Connections for Indirect Radiators

Diameter of Pipe	Indirect Radiating Surface Supplied
1 inch	40 sq. ft.
1¼ inches	70 " "
1½ "	100 " "
2 "	180 " "
2½ "	330 " "
3 "	600 " "
3½ "	900 " "
4 "	1,200 " "
4½ "	1,600 " "
5 "	2,100 " "
6 "	3,400 " "
7 "	5,400 " "
8 "	7,200 " "

supply and the return mains, and drop in pressure means a greater velocity in the pipes, and consequently a greater flow of steam to the radiators.

Indirect radiators are seldom tapped larger than 2 inches; therefore radiators that require larger connections should be subdivided in groups.

STEAM PRESSURES AND TEMPERATURES

Steam pressures and temperatures have a certain definite relation to each other, the temperature increasing with the pressure, but not as rapidly for a given increase with high-pressure as with low-pressure steam. For example, with an increase in pressure from 10 pounds to 20 pounds, the temperature rises about 19° F.; whereas with an increase of 10 pounds from 90 to 100 pounds the temperature increases only about 7° F. From atmospheric pressure to 10 pounds' gauge pressure, the increase in temperature is nearly 28° F; a slight difference in the pressure in radiators making a marked difference in their temperature.

TABLE VII

Temperature of Steam at Various Pressures

Vacuum (in Inches of Mercury)	Temp. °F.	Gauge Pressure (lbs. per sq. in.)	Temp. °F.
0	212.1	0	212
5	203.1	1.3	216.3
10	192.4	2.3	219.4
12	187.5	3.3	222.4
14	182.1	4.3	225.2
16	176.0	5.3	227.9
18	169.4	10.3	240.0
20	161.5	20.3	259.2
22	152.3	30.3	274.3
24	147.9	40.3	286.9
26	125.6	50.3	297.8
28	101.4	60.3	307.4
		70.3	316.0
		80.3	323.9
		90.3	331.1
		100.3	337.8
		150.3	365.7
		200.3	387.7

In the case of a *partial vacuum,* so called—expressed generally in inches of mercury—the decrease in temperature as a condition of perfect vacuum is approached is very marked, as shown in table VII, which gives also steam temperatures corresponding to various pressures. The latter are given in each case $\frac{3}{10}$ of a pound in excess of the gauge pressure, as practically all tables of the properties of steam give the absolute pressure—that is, the pressure above a vacuum—the absolute pressure corresponding to 5.3 pounds' gauge pressure, for example, being 20 pounds absolute.

The atmospheric pressure at sea-level is practically 14.7 pounds absolute, and the boiling point of water is 212°. As the pressure decreases, due to altitude or to the removal of air from a vessel by artificial means, the boiling point falls.

EXPANSION

Amount of Expansion. An allowance of $\frac{8}{1000}$ of an inch per 100 feet of pipe for each degree rise in temperature, is a fair allowance in computing the amount of expansion that will take place in a line of pipe.

One must assume the temperature at which the pipe will be put up—say anywhere from 0° to 40° in an unfinished building in winter—and, knowing the pressure to be carried, look up in a table of the properties of saturated steam the temperature corresponding. See table VII.

Example. Find the expansion that will take place in a line 100 feet long put up in 30-degree weather, when it is filled with steam at 80 pounds' pressure. The temperature corresponding to 80 pounds' steam pressure is 324°; the increase from 30° is 294°, which multiplied by $\frac{8}{1000}$ gives $2\frac{35}{100}$ inches expansion, or, expressed in decimals, 2.35 inches.

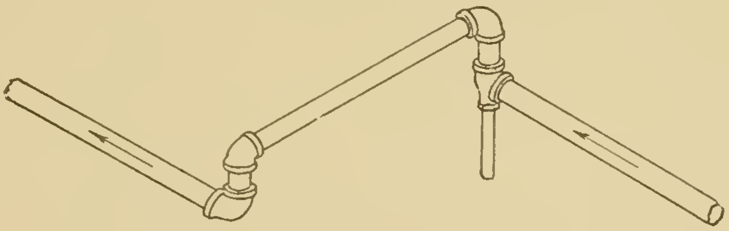


Fig. 23. Offset and Swivels.

In low-pressure work 100 feet of pipe heated from 30° to 230° will expand about 1.6 inches.

Provision for Expansion. The expansion of mains can generally be provided for by offsets and swivels, as shown in Fig. 29. All that is necessary is to have the two vertical nipples placed far enough apart, as determined by the length of the horizontal offset, to permit the expansion to take place without too much turning on the threads. The less the turn, the less will be the likelihood of leakage. The shorter the offsets, the greater the number that must be used.

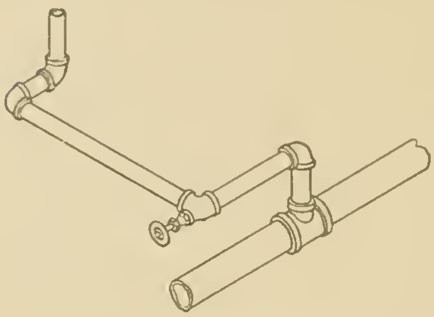


Fig. 30. Swing to Allow for Expansion of Risers.

A pretty conservative rule would be to allow 4 feet of offset to each inch of expansion to be taken up on the line. In the case of underground work a good deal of the expansion can be taken up where pipes enter buildings by the same kind of swings as shown in Fig. 29, making them longer and thus reducing the number of expansion joints or offsets in the tunnel or duct.

Expansion of Risers. In providing for the expansion of risers, considerable skill must be used, especially in tall buildings. In buildings of not over 6 to 8 stories, or possibly 10 floors at the outside, if they are not high-studded, the expansion may all be taken up in the basement, using swings like those shown in Fig. 30, similar swings being used in the attic also if the overhead-feed system is used, the connections being taken from the bottom of the main, as previously stated.

In higher buildings than those mentioned, either slip-pattern expansion joints or swivels made up of pipe and fittings are commonly used. One of these to every six to eight floors is generally considered sufficient, depending on the length and arrangement of the radiator connections. One must be sure the pipes above and below slip joints are in proper alignment; otherwise, binding and leakage will occur. If the risers are concealed, such joints must be made accessible through proper openings in the walls, as the packing will have to be taken up from time to time and replaced.

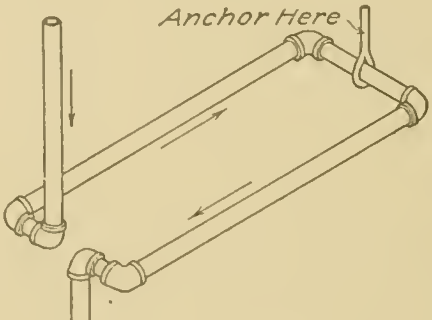


Fig. 31. Expansion Joints. Offsets Nearly Horizontal.

Expansion joints made up of pipes are illustrated in Fig. 31. Such joints are unsightly if exposed; but they may generally be concealed either in specially provided pockets in the floor or in spaces furred down below the ceilings and near the walls.

When expansion joints are used, the risers should be anchored about midway between them. These anchors consist merely of clamps around the pipes fastened to the beams, one type being shown in Fig. 32.

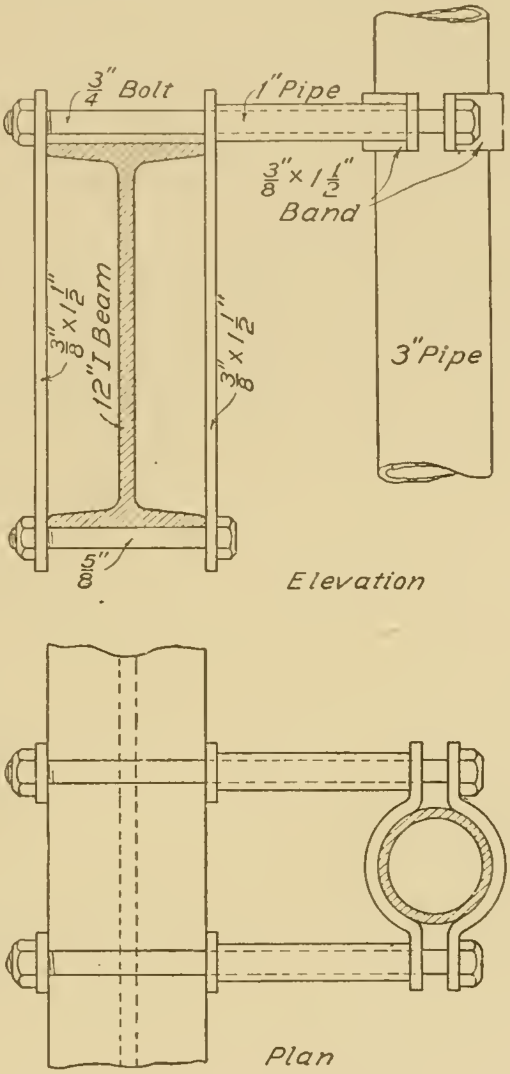


Fig. 32. Anchor for Riser.

Radiator Connections. Considerable ingenuity is exhibited by good fitters in arranging radiator connections. One should always study the end sought, and then provide the necessary means to secure that end. For example, on a floor at which the riser is anchored, almost any sort of radiator connection will answer, since expansion need not be provided for.

Where expansion takes place, swivels must be provided in the radiator connections, to allow for same. Fig. 33 shows a convenient way of taking off radiator connections from risers, any expansion being taken up by the turning of the horizontal connection in the parallel nipples. The connection should of course pitch back toward

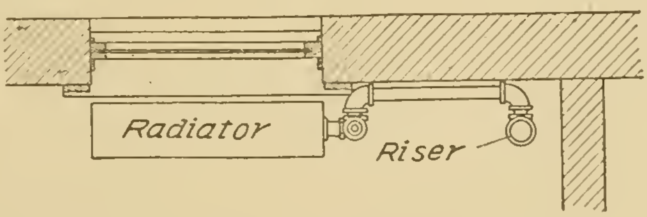


Fig. 33. Radiator Connections from Riser.

the riser, to drain freely. Where the expansion is considerable, this is difficult to accomplish unless the radiator is slightly raised.

When risers must be located along the same wall as that on which the radiator is placed, the swivels may be arranged as shown in Fig. 34.

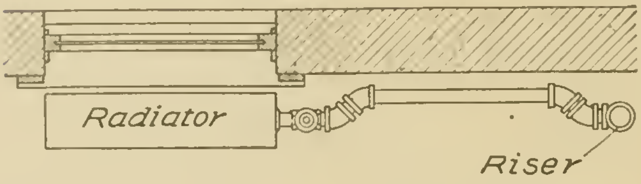


Fig. 34. Arrangement of Swivels when Risers are Located on the Same Wall as Radiator.

Radiators on the first floor have their connections made by angle valves with the pipes in the basement, to avoid running along the base-board. It is well to take the branch to the first-floor radiators from riser connections in the basement, rather than to cut into the mains for these branches. See Fig. 35.

COMPUTING RADIATION

Computing Direct Radiation. It is a perfectly simple matter to compute the amount of radiation required to heat a room, by finding the probable loss of heat per hour, and dividing this by the heat given off by a square foot of radiating surface in the same time.

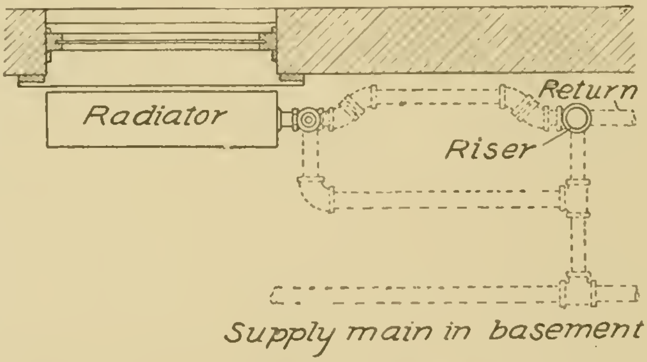


Fig. 35. Branch from Riser Connection in Basement.

Numerous tests have shown that an ordinary cast-iron radiator gives off approximately 1.6 heat units per hour per degree difference in temperature between the steam and the surrounding air. With low-pressure heating a square foot of direct radiation is commonly rated at about 250 H. U. Glass transmits about 85 heat units per square foot per hour, with 70° inside and 0° out; and walls of ordinary thickness may be reckoned as transmitting one-fourth as much heat.

The heat losses stated should be increased about 25 per cent for a north or west exposure, and about 15 per cent for an easterly exposure.

An allowance should be made for reheating rooms that are allowed to cool down slightly at night. This may be done most conveniently by adding to the loss of heat through walls and glass a number of heat units equal to 0.3 of the cubic contents of a room with two exposures, and 0.6 the contents of a room with a single exposed wall.

The way this works out may best be shown by a couple of examples:

Suppose we have a room 16 feet square and 10 feet high, with two exposed walls facing respectively north and west, each having a window three feet 6 inches by 6 feet.

Exposure of room = (16 + 16) × 10 =	320 sq. ft.
Glass surface = 2 × 21 sq. ft. =	42 " "
Net wall	278 sq. ft.
Equivalent glass surface (E. G. S.) of net wall = 278 ÷ 4 = Approximately	70 sq. ft.
Actual glass surface =	42 " "
Total E. G. S. Approximately	112 sq. ft.
Heat transmitted = 112 sq. ft. × 85 heat units × 1.25 factor =	11,890 H. U.
Allowance for reheating = 0.3 × cubic contents of 2,560 cu. ft. =	768 " "
Total heat loss to be made good by direct radiation	12,658 H. U.

This 12,658 heat units, divided by 250, the amount given off by one square foot of radiation in one hour, = 50 sq. ft. approximately, giving a ratio of 1 sq. ft. of radiating surface to 53 cubic feet of space.

Take as a second example a room with one exposure toward the east, the dimensions of the room being 14 by 14 by 10 feet, with one window 4 by 6 feet. Proceeding as before,

Exposure =	196 sq. ft.
Glass =	24 " "
Net wall	172 sq. ft.
E. G. S. of net wall = $\frac{1}{4}$ of same =	43 " "
Add actual glass =	24 " "
Total E. G. S.	67 sq. ft.
Heat loss per hour = 67 × 85 × 1.15 =	6,549 H. U.
Add 0.6 the contents to allow for reheating; 0.6 × 1,960 =	1,176 " "
Total heat loss	7,725 H. U.

This 7,725 heat units ÷ 250 = 31 sq. ft. radiation required, giving a ratio of 1 to 63 cubic ft.

The loss of heat through roofs and through ceilings to unheated attic spaces above may be allowed for conveniently, and with sufficiently close approximation to the actual heat loss, by dividing the area of the roof by 10, and that of the ceiling by 20, to give the E. G. S.

In the case of a well-constructed plank roof, with paper or other material above that will prevent the leakage of air, the roof area may safely be divided by 15 to ascertain the E. G. S.

It is hardly necessary, as a rule, to allow for the loss of heat through a first floor to the basement when the latter is well enclosed and contains steam and return mains or is otherwise kept at a moderate temperature.

Computing Direct-Indirect Radiation. The most common method of computing the amount of direct-indirect radiation required, is to ascertain, in the manner described, the direct radiating surface necessary, and add to it approximately 25 per cent; that is, if a direct radiator of 100 square feet were found to be necessary to heat a given room, a direct-indirect radiator of 125 square feet would be required.

Computing Indirect Radiation. To compute the amount of indirect radiation necessary to heat a given room, about the simplest method to grasp is to compute, first, the direct radiation required, as previously explained, and then add 50 per cent to this amount, since it happens that, under average conditions of 70° inside and 0° outside, practically $1\frac{1}{2}$ times as much surface is required to heat a given space with indirect as with direct heating.

When a stated air supply is required, the loss of heat by ventilation must be computed, and a different method followed in ascertaining the amount of indirect radiation required. For example, take a 50-pupil schoolroom with the common compulsory allowance of 30 cubic feet of air per minute per pupil—equal to 1500 cubic feet per minute per room. Each cubic foot escaping up the vent flue at 70° F., when the outside temperature is zero, removes from the room $1\frac{1}{4}$ heat units; hence the total heat loss by ventilation per hour would be $60 \times 1500 \times 1\frac{1}{4} = 112{,}500$ heat units. A standard schoolroom has about 720 square feet of exposure, of which not far from 180 square feet is glass, leaving a net wall of 540 square feet, which, divided by 4, gives 135 square feet equivalent glass surface. This, added to the actual glass, gives 315 square feet E. G. S., which, in turn, multiplied by 85 heat units × a factor of 1.25 for north or west, gives a total heat loss by transmission of 33,470 heat units approximately.

The combined loss of heat by transmission and ventilation amounts to 145,970 H. U.

With the greater air-flow through indirect heaters used in schools, the heat emitted per square foot per hour should exceed somewhat the amount given off by indirect radiators in residence work—namely, 400 H. U. To be on the safe side, allow 450 H. U. The total heat loss from the room, divided by this number, gives approximately 300 square feet as the surface required.

DUCTS, FLUES, AND REGISTERS

Areas of Ducts and Flues. The area of the cold-air connections with the benches or stacks of indirect radiators, are generally based on 1 to $1\frac{1}{4}$ square inches of area to each square foot of surface in the radiators.

The flues to the first floor should have $1\frac{1}{2}$ to 2 square inches area to each square foot of surface; those to the second floor, $1\frac{1}{4}$ to $1\frac{1}{2}$ square inches; and those to floors above the second, 1 to $1\frac{1}{4}$ square inches per square foot of radiation.

The sides and back of warm-air flues in exposed walls should be protected from loss of heat by means of a nonconducting covering, preferably $\frac{1}{2}$ inch thick.

Flue Velocities. A fair allowance for flue velocities with indirect steam heating is 275 feet per minute for the first floor, 375 feet for the second, 425 feet for the third, and 475 for the fourth.

Registers. The net area of registers should be 10 to 25 per cent in excess of the area of the flue with which they are connected. The net area of a register is commonly taken as $\frac{2}{3}$ the gross area; that is, a 12 by 15-inch register would have a net area of 120 square inches.

Registers in shallow flues must either be of the convex pattern, or be set out on a moulding to avoid having the body project into the flue and cut off a portion of its area.

Aspirating Heaters and Coils. To cause a more rapid flow of air in ventilating flues in mild weather, steam coils or heaters are used. These should be placed as far below the top of the vent flue as possible, for the higher the column of heated air, the greater the chimney effect. The smaller the flue in proportion to the volume of air to be handled, the larger should be the heater. If cast-iron indirect radiators are used, they may be rated to give off about 350 heat units per square foot per hour; coils may be rated to give off nearly double that number of heat units.

To illustrate how to compute the size of coil to be used, assume for example that 1,500 cubic feet per minute are to be removed through a ventilating flue, the air to be raised 10° in temperature. Then

$$\frac{1{,}500 \text{ cu. ft. per min.} \times 60 \text{ min. per hour} \times 10^\circ \text{ rise in temp.}}{55 \text{ heat units} \times 650 \text{ heat units per hour per sq. ft. of coil}} = 25.+ \text{ sq. ft. of coil required.}$$

(The number 55 is the number of cubic feet of air at 70° that 1 heat unit will raise 1° F.)

In order to work out important problems of this nature, it is necessary to consult a table giving flue velocities for different heights and for excesses of temperature of air in the flue over that out of doors. From such a table, knowing the height of the flue, its size, and the volume of air to be moved, it is readily seen how many degrees the air must be heated. The size of coil is then determined as above. The arrangement of an aspirating heater in a flue is shown in Fig. 36.

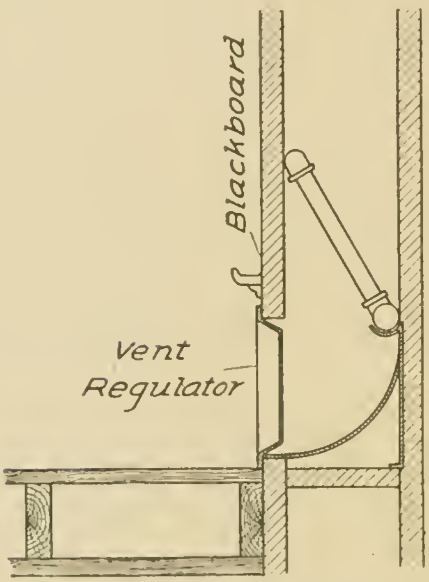


Fig. 36. Aspirating Regulator in Flue.

EXHAUST-STEAM HEATING

Buildings having their own power and lighting plant should be heated by exhaust steam, about 90 per cent of the steam that passes through the engines and pumps being available for this purpose.

A portion of this steam is used for heating the feed-water to the boilers. In a properly arranged system, very little fresh water need be supplied, since the condensation from the radiators, properly purified, is returned to the boilers.

To accomplish this purification, and to rid the steam of oil in order to prevent its coating the pipes and radiators, the steam is passed through a separator attached to the heater when all the steam is allowed to enter it, or through an independent separator when only a portion of the steam passes through the feed-water heater. Only about one-sixth of the exhaust steam in a given plant is required to heat the feed-water that must be supplied to the boilers to take the place of the steam used in the engines, therefore all the exhaust need not enter the heater for the purpose of keeping up the proper temperature of the feed-water.

A type of heater with a coke fitter is shown in Fig. 37; while Figs. 38 and 39 show two methods of making connections, the first when all the steam is allowed to pass through the heater, the latter when only a portion of the exhaust from the engines is allowed to enter.

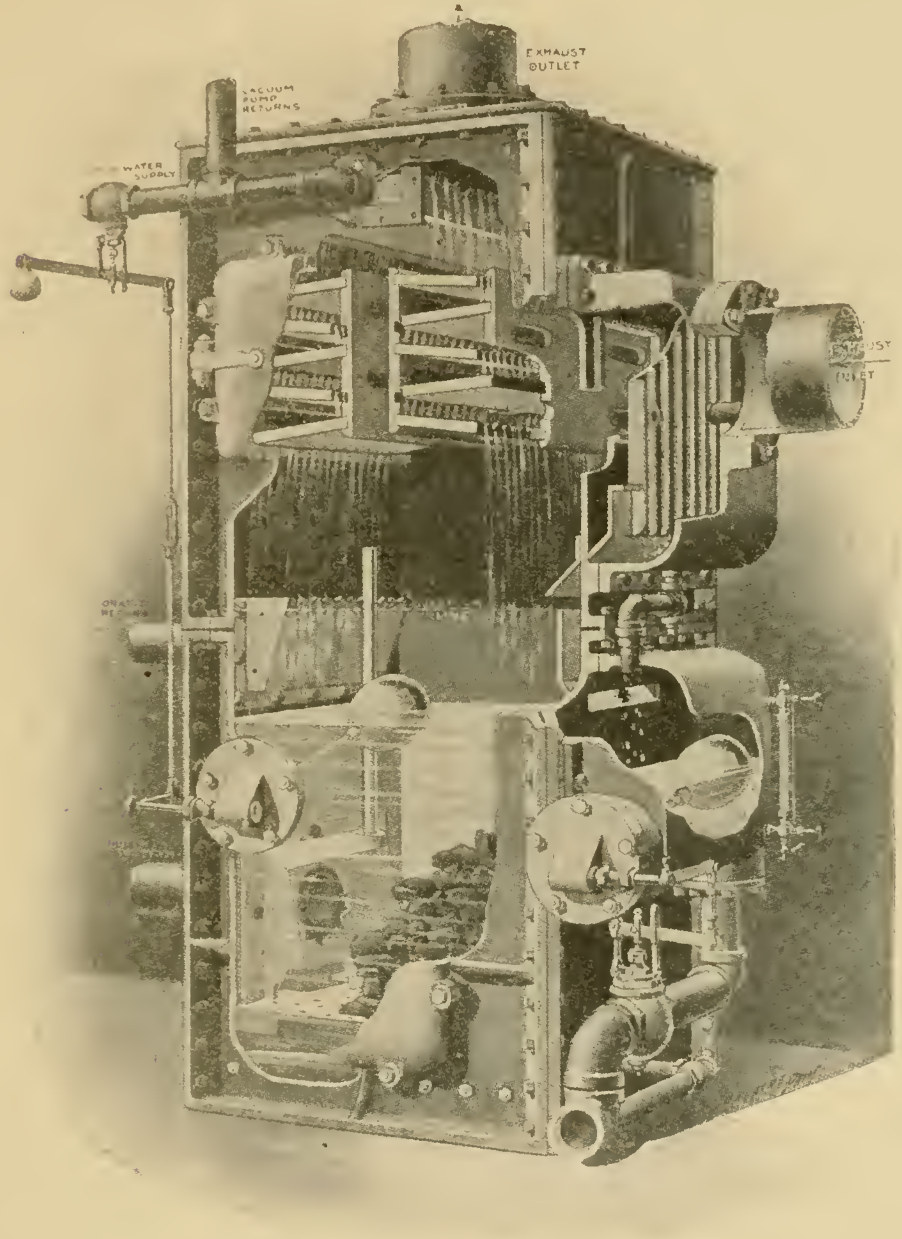


Fig. 37. Heater with Coke Fitter.

A very essential appliance used with exhaust-steam heating is the *pressure-reducing valve*, which makes good with live steam any deficiency in exhaust that may occur. By adjusting the weight, any desired pressure, within limits, may be obtained.

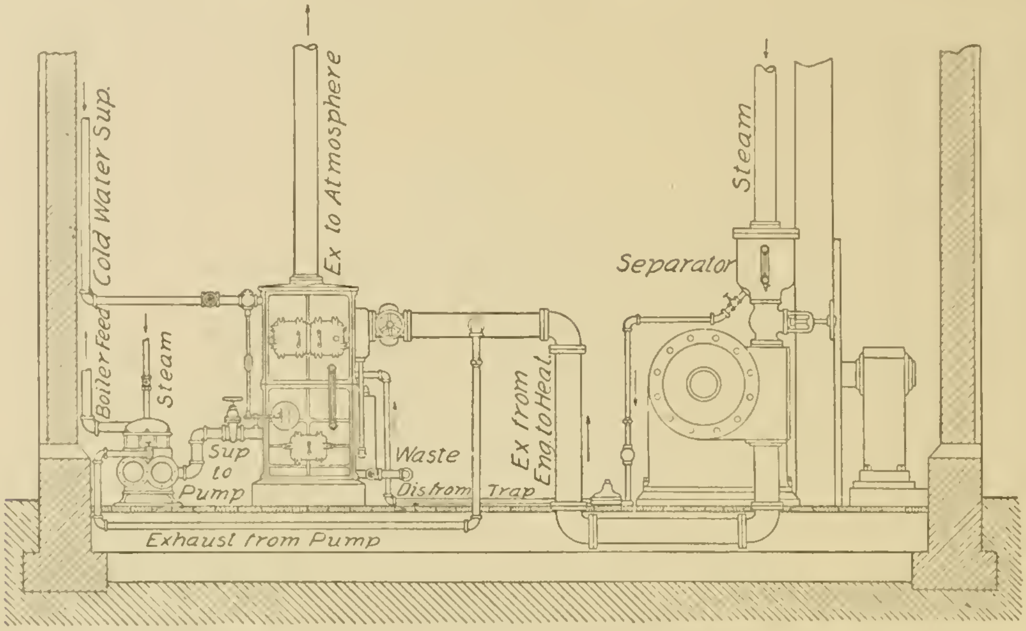


Fig. 38. Method of Making Connections when All the Steam is Allowed to Pass Through the Heater.

A *back-pressure valve* must be used with exhaust-steam heating, to regulate the pressure to be carried. It also acts as a safety-valve in case of over-pressure from any cause.

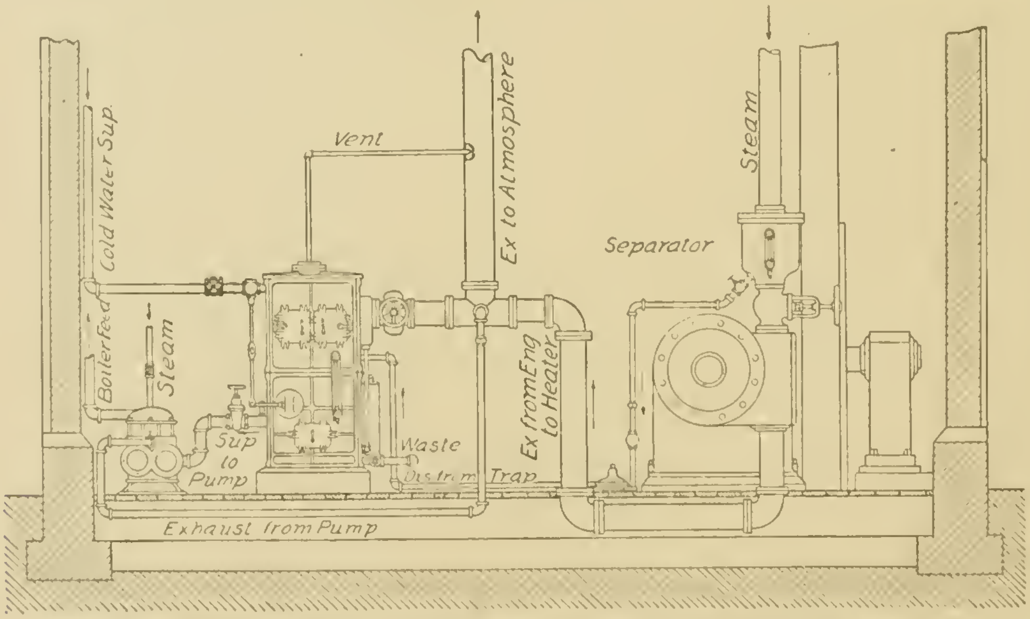


Fig. 39. Method of Making Connections when Only a Portion of Exhaust from Engine is Allowed to Enter.

Heating systems are sometimes arranged by bringing to them live steam to be reduced in the building to any desired pressure by a reducing valve. In such cases there is no back-pressure valve; therefore a safety-valve should be placed on the main to act in case of trouble with the reducing valve and prevent too great a pressure on the radiators.

A by-pass should be used in connection with all pressure-reducing valves, to provide for overhauling them. A steam gauge connected not less than 6 feet from the valve on the low pressure side is a necessary attachment.

With exhaust-steam heating, an exhaust head should be placed at the top of the vertical exhaust main, to condense, as far as possible, the steam passing through it.

The drip pipe from the exhaust should be connected with the drip tank; or, if the exhaust has been passed through a first-class separator, it may, if desired, be returned to the feed-water heater.

When a closed type feed-water heater is used (see Fig. 40), a separate tank must be provided for the returns from the heating systems. High-pressure drips are trapped to this tank. In the case of the heater shown in Fig. 37, the live-steam returns are trapped to it. A common type of trap is shown in section in Fig. 41. In the position shown, the float or bucket hinged as shown, is held up by the buoyancy of the water, and keeps the valve at the upper end of the spindle in contact with the seat, preventing the escape of steam entering with the water through the inlet. The water, rising around the bucket, overflows it and overcomes its buoyancy, causing it to fall and open the valve, the steam pressure on the water then forcing it out of the bucket until a point is reached where

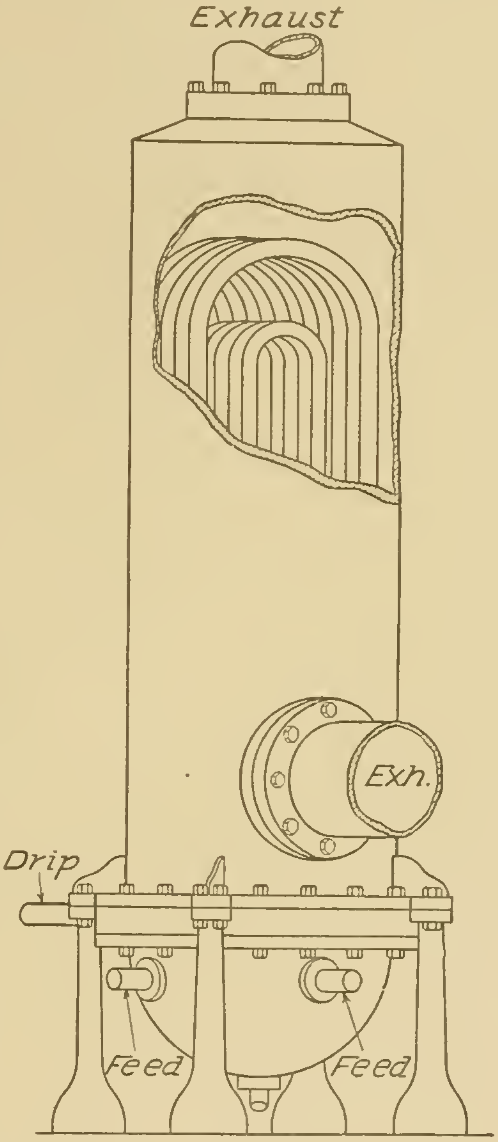


Fig. 40. Closed Type Feed Water Heater.

the buoyancy of the bucket again comes into play and closes the valve until the action is again repeated.

An extremely simple form of float trap is shown in Fig. 42, the hollow float raising the spindle and valve, permitting water to escape, but falling and thus closing the outlet when the water level reaches a point too low to cause the ball to float, thus preventing the escape of steam.

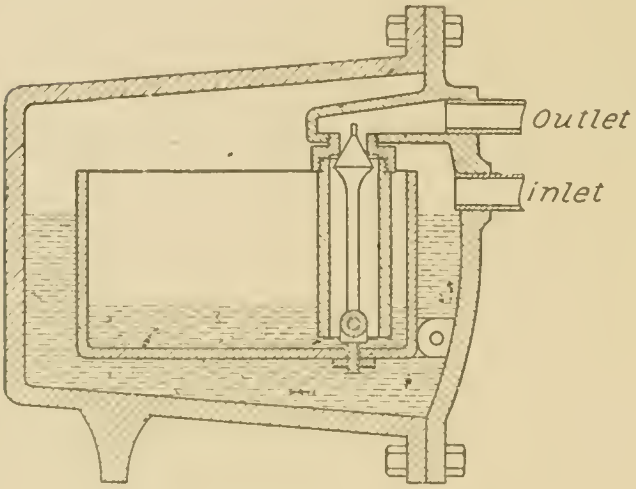


Fig. 41. Common Type of Trap.

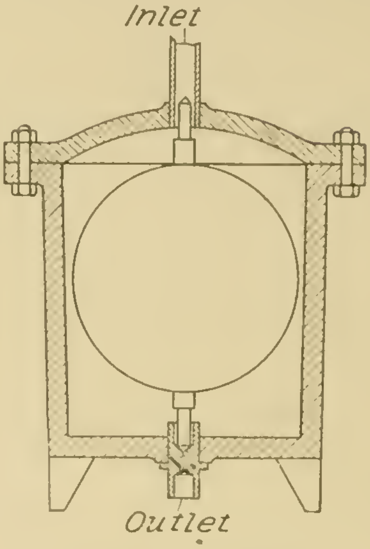


Fig. 42. Float Trap.

Special forms of traps known as *return traps* are used in small plants for returning to the boiler the condensation from the heating system.

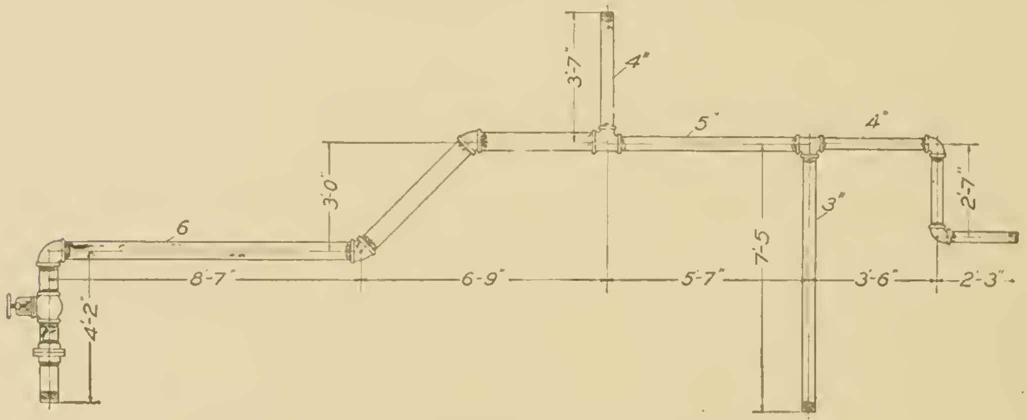
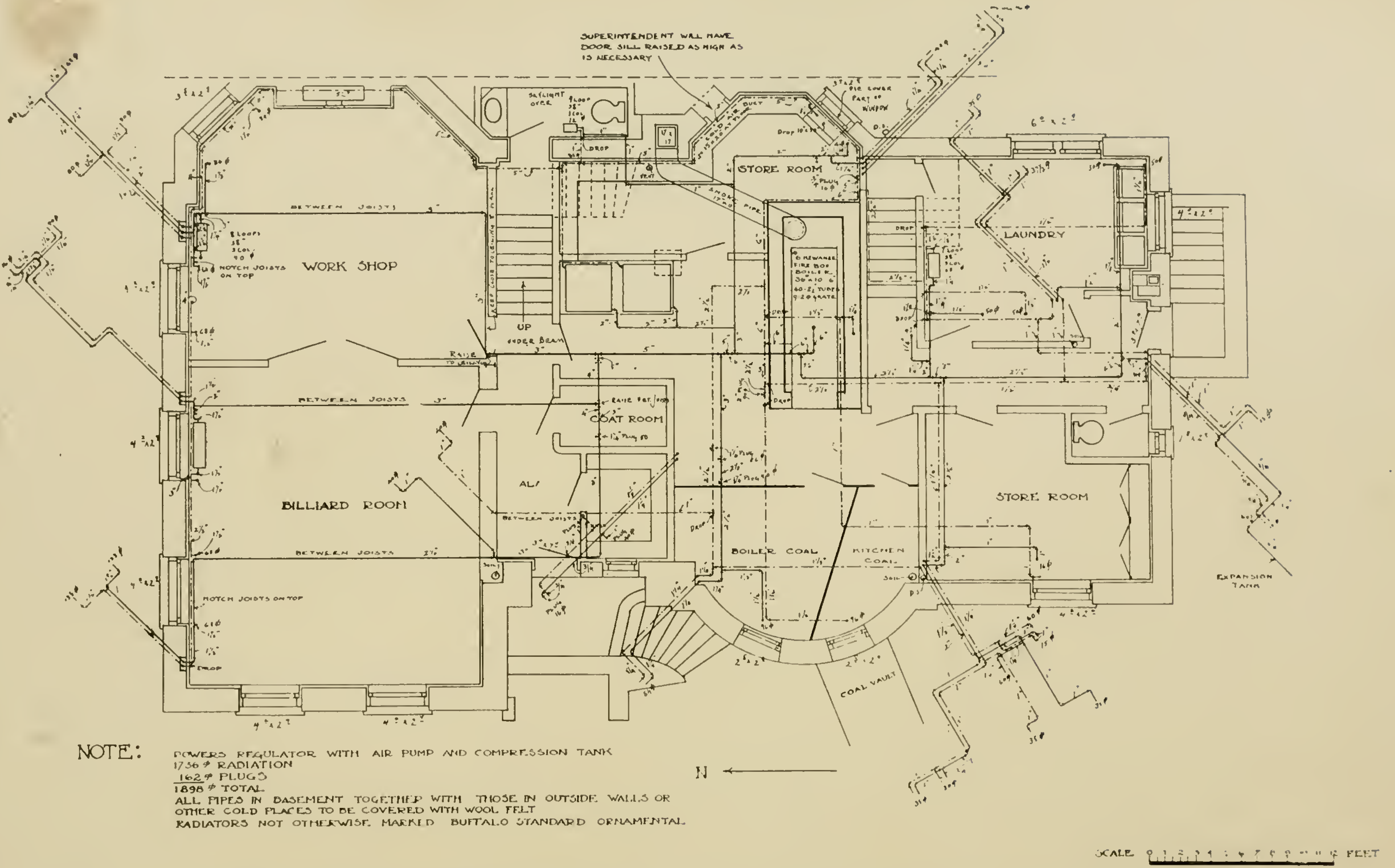


Fig. 43. Dimensioned Sketches for Cutting Pipe.

MODIFIED SYSTEMS OF STEAM HEATING

It is beyond the scope of this course to go into the details of the various modified or patented systems of steam circulation, yet it seems

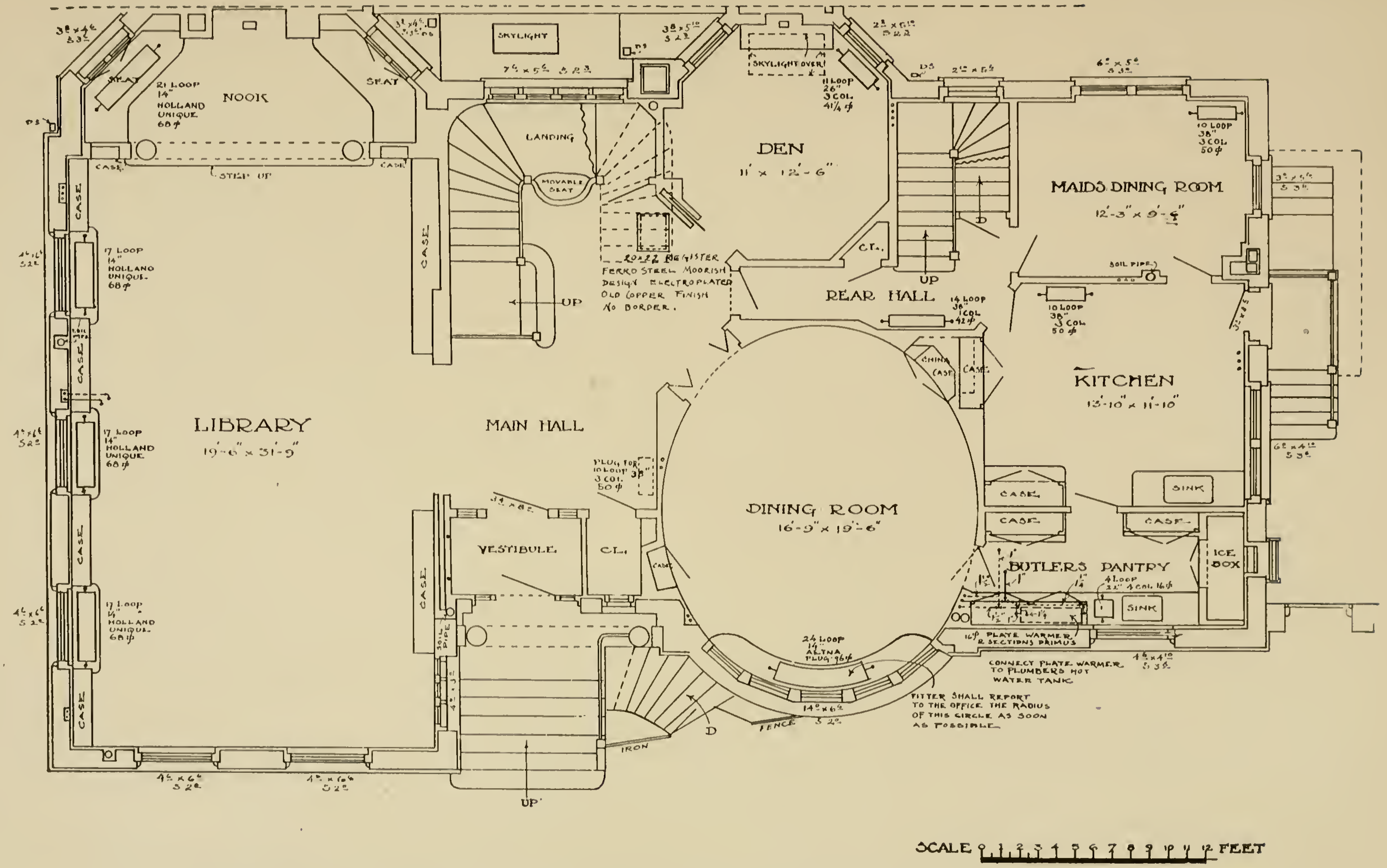


NOTE: POWERS REGULATOR WITH AIR PUMP AND COMPRESSION TANK
1736 # RADIATION
162 # PLUGS
1898 # TOTAL
ALL PIPES IN BASEMENT TOGETHER WITH THOSE IN OUTSIDE WALLS OR OTHER COLD PLACES TO BE COVERED WITH WOOL FELT
RADIATORS NOT OTHERWISE MARKED BUFFALO STANDARD ORNAMENTAL

BASEMENT PLAN OF RESIDENCE OF MRS. JAMES H. BARNARD, SHOWING LAYOUT OF HOT-WATER HEATING PLANT

W. Carbys Zimmerman, Architect, Chicago, Ill.

Heating plant installed in 1904.


NOOK
21 LOOP 14" HOLLAND UNIQUE 68 ¢
SEAT
SEAT
SKYLIGHT
LANDING
MOVABLE SEAT
DEN
11' × 12'-6"
SKYLIGHT OVER
11 LOOP 26" 3 COL. 41¼ ¢
MAIDS DINING ROOM
12'-3" × 9'-5"
10 LOOP 38" 3 COL 50 ¢
SOIL PIPE
KITCHEN
13'-10" × 11'-10"
10 LOOP 38" 3 COL 50 ¢
REAR HALL
UP
D
CL.
14 LOOP 38" 1 COL 42 ¢
CHINA CASE
CASE
20×22 REGISTER FERRO STEEL MOORISH DESIGN ELECTROPLATED OLD COPPER FINISH NO BORDER.
STEP UP
CASE
LIBRARY
19'-6" × 31'-9"
17 LOOP 14" HOLLAND UNIQUE 68 ¢
17 LOOP 14" HOLLAND UNIQUE 68 ¢
17 LOOP 14" HOLLAND UNIQUE 68 ¢
SOIL PIPE
MAIN HALL
UP
PLUG FOR 10 LOOP 38" 3 COL 50 ¢
VESTIBULE
CL.
DINING ROOM
16'-9" × 19'-6"
24 LOOP 14" ALTNA PLUG 96 ¢
CASE
SINK
ICE BOX
BUTLERS PANTRY
4 LOOP 32" 4 COL 16 ¢
SINK
16 ¢ PLATE WARMER 2 SECTIONS PRIMUS
CONNECT PLATE WARMER TO PLUMBERS HOT WATER TANK
FITTER SHALL REPORT TO THE OFFICE THE RADIUS OF THIS CIRCLE AS SOON AS POSSIBLE
FENCE
IRON
D
UP
SCALE 0 1 2 3 4 5 6 7 8 9 10 11 12 FEET

FIRST-STORY PLAN OF RESIDENCE OF MRS. JAMES H. BARNARD, SHOWING LAYOUT OF HOT-WATER HEATING PLANT

W. Carbys Zimmerman, Architect, Chicago, Ill.

For Second and Third Story Plans, See Page 186; for Exterior, See Page 131.

advisable to point out the essential features of certain of these systems. The Webster and Paul Systems will be found described in Part III of the Instruction Paper on Heating and Ventilation.

Thermograde System. With this two-pipe system air valves are omitted; the supply valve on each radiator is of a special construction designed to be set to admit quantities of steam under different conditions—to fill the radiator $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, or entirely full of steam. On the return end of each radiator is placed a so-called *auto-valve*, designed to permit the escape of air and water into a return pipe open to the atmosphere at the top. In the case of large buildings the water flows by gravity to a tank, from which it is pumped to the boilers.

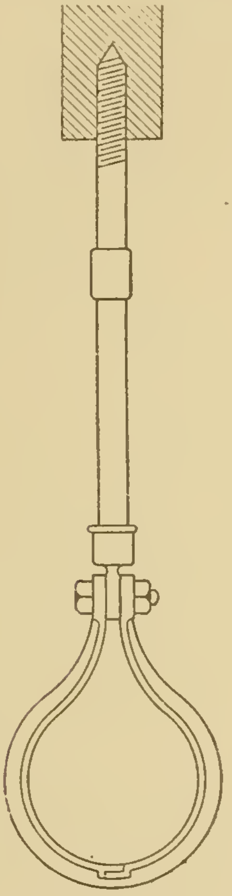


Fig. 44. Hanger.

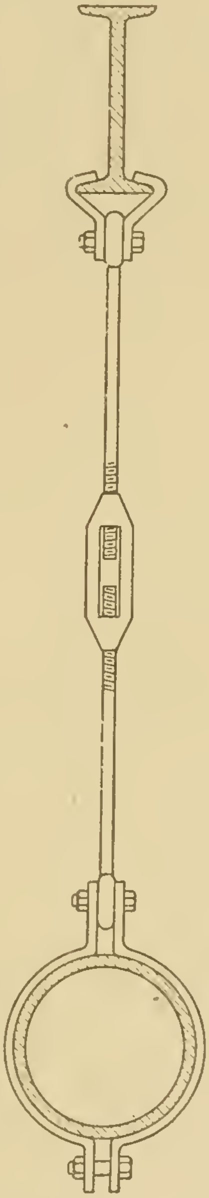


Fig. 45. Adjustable Hanger for Large Pipe.

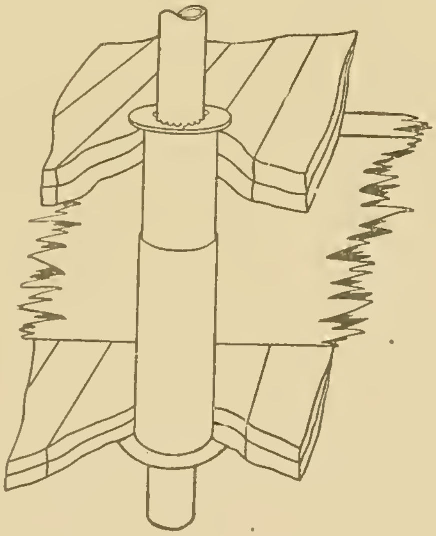


Fig. 46. Sleeve for Encasing Pipe.

Some of the advantages claimed for this system are:—Absence of air-valves and air-lines; control of the heat emitted, by means of the special controlling valve at the supply end of each radiator. The piping is the same as for ordinary gravity systems.

Vapor System. This system is designed, as its name implies, to work on a very low pressure. The radiators, preferably of the hot-water type, must have considerably more surface than with low-pressure steam heating. A special valve is placed at the supply end of each radiator, designed to admit any desired volume of steam.

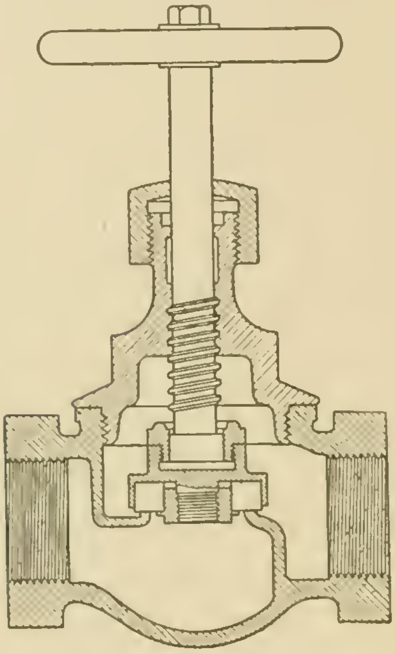


Fig. 47. Globe Valve.

A little trap or water-seal fitting is connected with the return end of each radiator, a small hole being provided above the water line to permit the escape of air. All returns are joined in the basement and discharge to an open water column alongside the boiler, any steam in the returns being condensed by passing into a coil provided for the purpose.

No safety valve is required with this system. In case of an excess of pressure in the boiler, the water is backed out into the column above mentioned; a float is raised; and dampers are closed.

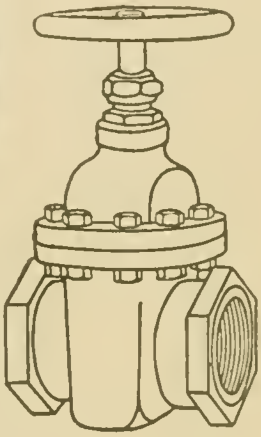


Fig. 48. Gate Valve.

The advantages claimed are:—Complete control of the heat given off by the radiators by means of the special regulating valve on each; absolute safety; small pipes; absence of air-valves.

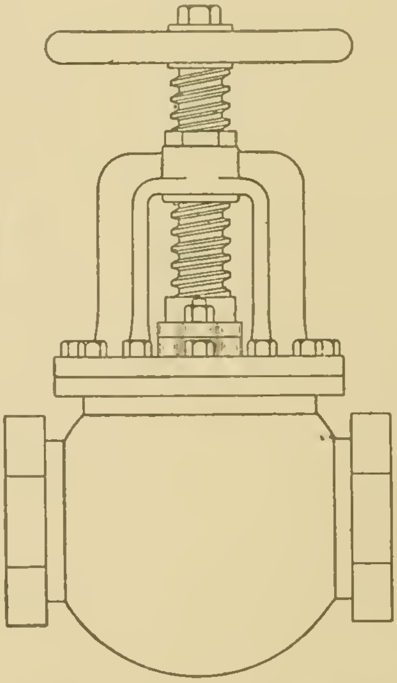


Fig. 49. Iron Body Globe Valve.

Mercury Seal Vacuum Systems. In one of these systems, commonly used with gravity-return apparatus, air-valves similar to those shown in Fig. 55 are placed on the radiators, and the air-lines connected with a main line discharging through a mercury seal or column, the function of which is to seal the end of the pipe and prevent the entrance of air after the air from the system has been expelled by raising the steam pressure. In another mercury seal system, air-valves are omitted and "retarders"—so called—are placed at the return ends of radiators.

With a tight job of piping when the air in the system has once been got rid of, the plant may be run for some time—or until air leaks in again—at a pressure less than the atmosphere and with radiators at temperatures corresponding to those of hot-water radiators.

Among the claims made for this system are:—Wide range of temperature in the radiators, secured by varying the degree of vacuum; the advantage of a hot-water heating system without large radiators, since steam under pressure can be carried in the radiators in cold weather.

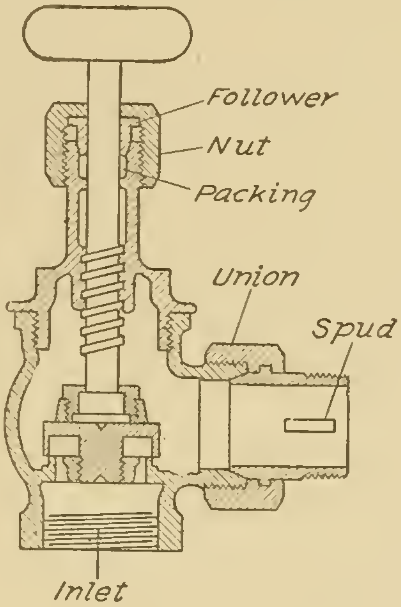


Fig. 50. Radiator Angle Valve.

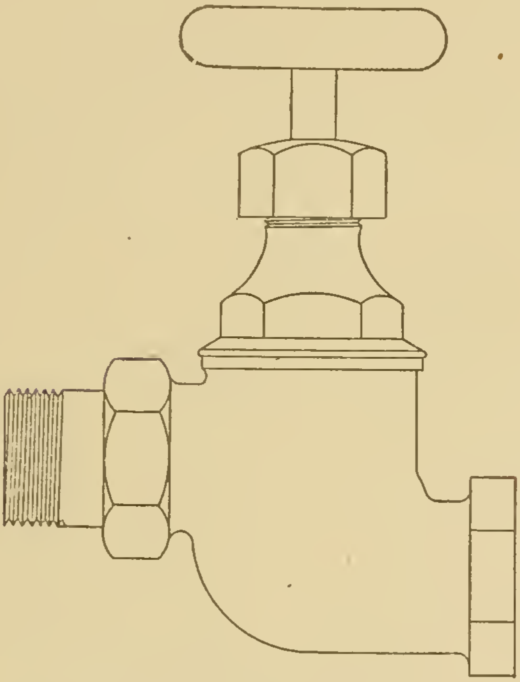


Fig. 52. Radiator Offset Valve.

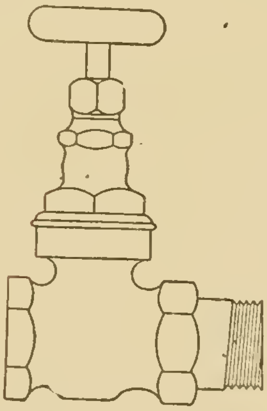


Fig. 51. Radiator Straightway Valve

PIPE AND FITTINGS

Pipe. Pipe for heating systems should be made of wrought iron or mild steel. Sizes up to $1\frac{1}{4}$ inches diameter inclusive, are butt-welded and proved to 300 pounds' pressure; above that size they are lap-welded and tested to 500 pounds' pressure.

TABLE VIII

Standard Weight Pipe Dimensions and Data

Diameters (Inches)			Areas (Square Inches)			Miscellaneous						
Nominal Diameter	Actual External Diameter	Actual Internal Diameter	External Area	Internal Area	Area of Metal	Thickness of Metal	Linear Feet per Square Foot of External Surface	Linear Feet to Contain One Cubic Foot	Pounds of Water per Linear Foot	Nominal Weight of Pipe per Foot (Pounds)	Threads per Inch	Taper of Threads per Inch of Screw
1/8	.405	.269	.1288	.0568	.0720	.068	9.14	2,500.	.024	.211	27	1/32
1/4	.540	.364	.2290	.1011	.1249	.088	7.075	1,385.	.011	.42	18	1/32
3/8	.675	.493	.3578	.1909	.1669	.091	5.657	751.5	.082	.559	18	1/32
1/2	.840	.622	.5512	.3039	.2503	.109	4.502	472.4	.132	.837	14	1/32
3/4	1.050	.824	.8659	.5333	.3326	.113	3.637	270.	.23	1.115	14	1/32
1	1.315	1.017	1.3581	.8609	.4972	.134	2.903	166.9	.373	1.668	11½	1/32
1¼	1.660	1.380	2.1612	1.4957	.6685	.140	2.301	96.25	.648	2.244	11½	1/32
1½	1.900	1.610	2.8353	2.0358	.7995	.145	2.01	70.65	.883	2.678	11½	1/32
2	2.375	2.067	4.4301	3.3558	1.074	.154	1.611	42.36	1.451	3.609	11½	1/32
2½	2.875	2.467	6.4918	4.7800	1.712	.204	1.328	30.11	2.072	5.739	8	1/32
3	3.500	3.066	9.6211	7.3827	2.238	.217	1.091	19.49	3.202	7.536	8	1/32
3½	4.000	3.548	12.566	9.886	2.680	.226	.955	14.56	4.285	9.001	8	1/32
4	4.500	4.026	15.904	12.730	3.174	.237	.849	11.31	5.517	10.665	8	1/32
4½	5.000	4.508	19.635	15.960	3.675	.246	.765	9.03	6.908	12.34	8	1/32
5	5.563	5.045	24.306	19.985	4.321	.259	.629	7.20	8.668	14.502	8	1/32
6	6.625	6.065	31.472	28.886	5.586	.280	.577	4.98	12.52	18.762	8	1/32
7	7.625	7.023	45.664	38.743	6.921	.301	.501	3.72	16.79	23.271	8	1/32
8	8.625	7.981	58.426	50.024	8.405	.322	.444	2.88	21.68	28.177	8	1/32
10	10.750	10.018	90.763	78.822	11.91	.366	.355	1.80	31.17	40.065	8	1/64
12	12.750	12.000	127.68	113.09	14.59	.375	.293	1.235	49.02	48.985	8	1/64

Circumference = Diameter × 3.1416.
1 cu. ft. = 7½ gallons.
1 gallon = 231 cu. inches.

1 cu. ft. of water weighs 62.4 lbs.
1 gallon of water weighs 8⅓ lbs.

Pipe is shipped in lengths of 16 to 20 feet, threaded on both ends and fitted with a coupling at one end.

It is well, as a rule, to have pipes 2½ inches in diameter and larger cut in the shop from sketches. These should give the distances from end to center, or center to center, and should state the size and kind of valves, whether flanged or screwed fittings are to be used, and in a general way should follow Fig. 43.

The dimensions of standard pipe are given in Table VIII.

NOTES ON WROUGHT-IRON PIPE

(Furnished by the Crane Company, Chicago, Ill.)

Wrought-Iron Pipe:—This term is now used indiscriminately to designate all butt- or lap-welded pipe, whether made of iron or steel.

Merchant Pipe:—This term is used to indicate the regular wrought pipe of the market, and such orders are usually filled by the shipment of soft steel pipe. The weight of merchant pipe will usually be found to be about five per cent less than card weight, in sizes ⅛-inch to 6-inch, inclusive; and about ten per cent less than card weight, in sizes 7-inch to 12-inch, inclusive.

Full-Weight Pipe:—This term is used where pipe is required of about card weight. All such pipe is made from plates which are expected to produce pipe of card weight; and most of such pipe will run full card to a little above card, but, owing to exigencies of manufacture, some lengths may be below card, but never more than five per cent.

Large O. D. Pipe:—A term used to designate all pipe larger than 12-inch. Pipe 12-inch and smaller is known by the nominal internal diameter, but all larger sizes by their external (outside) diameter, so that "14-inch pipe," if ⅜ inch thick, is 13¼-inch inside, and "20-inch pipe" of same thickness is 19¼-inch inside.

The terms "Merchant," or "Standard pipe," are not applicable to "Large O. D. pipe," as these are made in various weights, and should properly be ordered by the thickness of the metal.

When ordering large pipe threaded, it must be remembered that ¼-inch metal is too light to thread, $\frac{5}{16}$-inch being minimum thickness.

Orders for large outside diameter pipe, wherein the thickness of metal is not specified, are filled as follows:

Fourteen, fifteen, and sixteen inch, O. D., $\frac{5}{16}$-inch or ⅜-inch metal.

Larger sizes, ⅜-inch metal.

This pipe is shipped with plain ends, unless definitely ordered "threaded."

Extra Strong Pipe:—This term designates a heavy pipe, from ⅛-inch to 8-inch only, made of either puddled wrought iron or soft steel. Unless directed to the contrary, steel pipe is usually shipped. If wrought-iron pipe is required, use the term, "Strictly Wrought-Iron Extra Strong Pipe." Extra strong pipe is always shipped with plain ends and without couplings, unless instructions are received to thread and couple, for which there is an extra charge.

This term, when applied to pipe larger than 8-inch, is somewhat indefinite, as 9-, 10-, and 12-inch is made both $\frac{7}{16}$ and ½ inch thick. Pipes ½ inch thick are carried in stock, and furnished on open order.

Double Extra Strong Pipe:—This pipe is approximately twice as heavy as extra strong, and is made from ½ to 8 inches, in both iron and steel. It is difficult, however, to find any quantity in "Strictly Wrought-Iron," and the stock carried is usually soft steel. This pipe is shipped with plain ends, without couplings, unless ordered to thread and couple, for which there is an extra charge.

Fittings. For low-pressure heating systems, standard weight cast-iron screwed fittings are used on pipes up to 7 inches or 8 inches diameter. On larger pipes it is customary to use standard flanged fittings. Flange unions should be placed at intervals in the pipes when screwed fittings are used, to provide for readily disconnecting them in case of alterations or repairs.

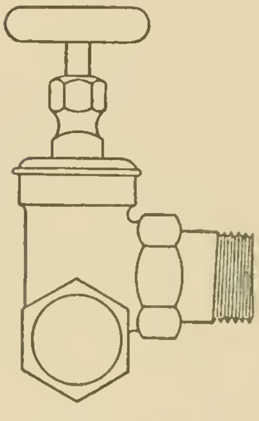


Fig. 53. Radiator Valve.

Pipe grease or various compounds are used in "making up" the joints. This material should be applied to the male threads only. When the threads of the fittings are coated with it, as is commonly done, the compound is pushed into the fitting when the pipe is screwed in, and, becoming disengaged, is likely to cause trouble later by clogging pipes, etc. For flange fittings it is the practice with many fitters to use inside gaskets, so called, cut to come just inside the bolts.

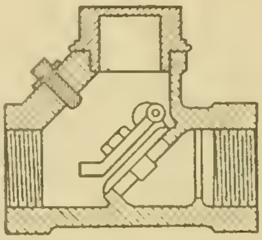


Fig. 54. Swing Check Valve.

To describe a tee; always give the dimensions of the "run" first and the outlet last; for example, a tee 6 inches at one end, 5 inches at the other, with an outlet at the side 3½ inches, would be known as a 6 by 5 by 3½ tee.

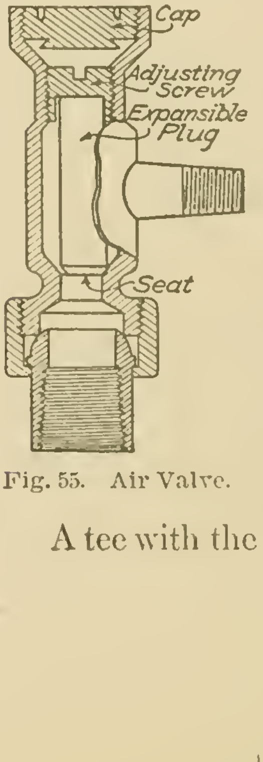


Fig. 55. Air Valve.

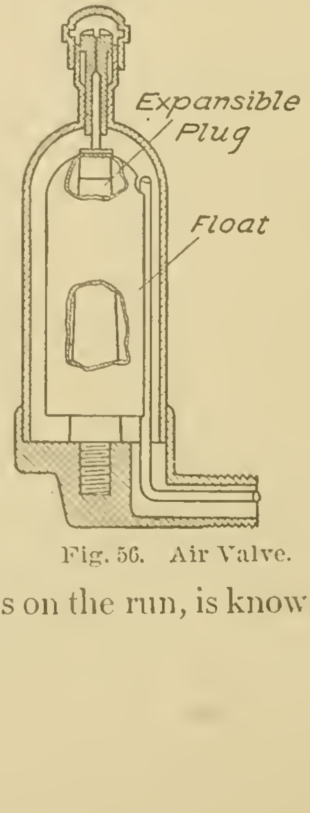


Fig. 56. Air Valve.

A tee with the outlet larger than the openings on the run, is known as a *bullhead* tee. Tees with all three openings of the same size are known as *straight* tees.

It is far better to use reducing sockets or reducing elbows and tees, in place of straight tees with bushings.

Hangers. Pipes up to 4 inches diameter inclusive are commonly suspended by malleable-iron hangers, one type of which is shown in Fig. 44, with a gimlet point on the rod, a beam clamp being substituted when I-beams are used in place of floor timbers. One form of adjustable hanger for large pipes is shown in Fig. 45.

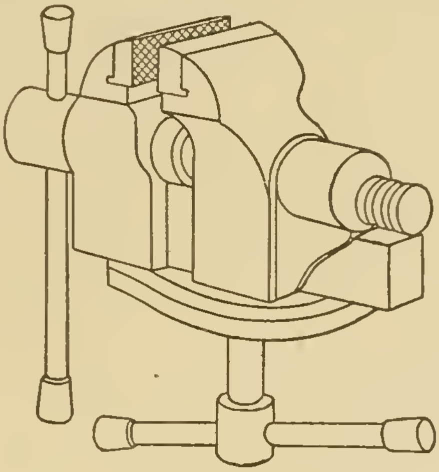


Fig. 58. Flat Jaw Vise.

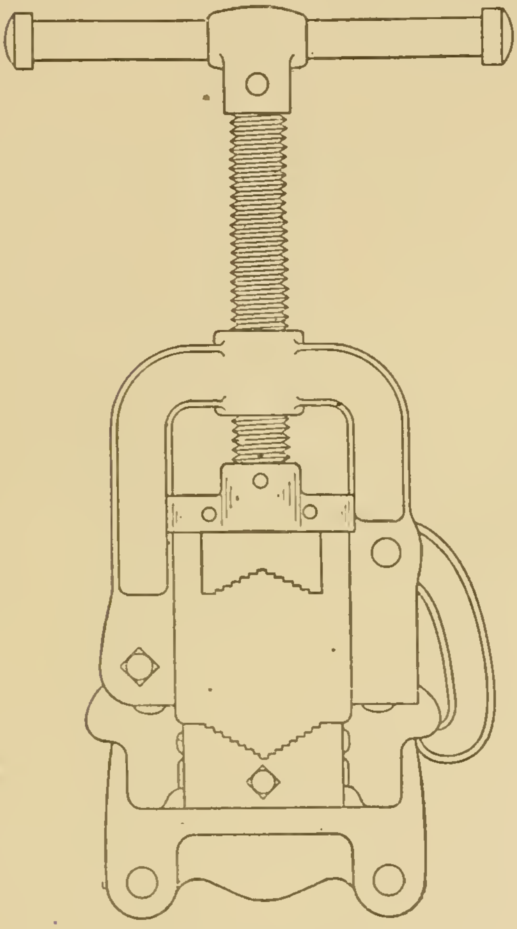


Fig. 57. Pipe Vise.

Sleeves, etc. Where pipes pass through floors and partitions, they are encased in tubes with plates at floor and ceiling or at walls, as the case may be. One type of these sleeves is shown in Fig. 46.

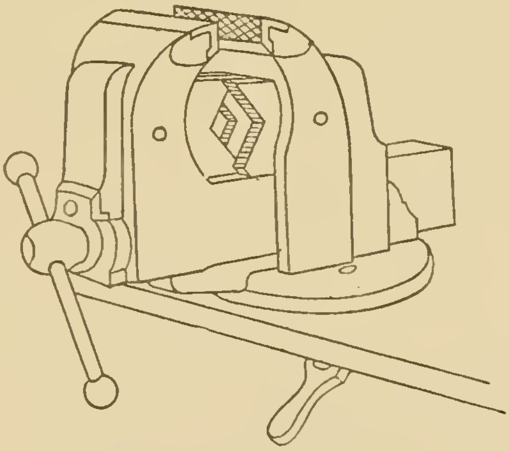


Fig. 59. Combination Vise.

Where branches from risers pass through partitions, it is often necessary to use sleeves of elliptical shape to provide for the expansion of the risers. Sleeves for mains passing through basement walls are generally made of pieces of wrought-iron pipe of the proper length, the diameter of the sleeves to be not less than ½ inch greater than the pipe diameter if covering is omitted in walls, and 2¼ inches greater if covering is continuous along the pipe.

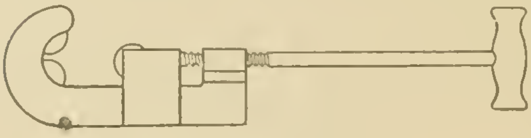


Fig. 60. Pipe Cutter.

When sleeves are placed in plastered walls, they should project a slight distance beyond the face of the plaster. When ceiling plates are made fast to risers, they should be placed at least ⅜ inch down from the ceilings, so that, when the riser expands, the ceiling plate will not be forced into the plaster.

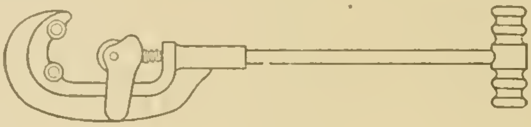


Fig. 61. Pipe Cutter.

Valves. Valves for basement piping are commonly *globe* or *gate* pattern, with rough bodies and plain iron wheels (Figs. 47 and 48). Brass or composition body valves, with screwed tops, are generally used up to 2-inch size inclusive; and iron body valves, with bolted tops, above that size (see Figs. 48 and 49). Both are made with renewable discs or seats.

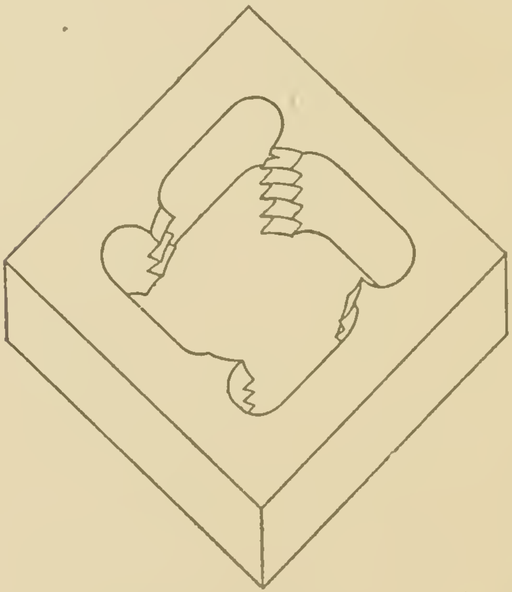


Fig. 62. Solid Die.

It is largely a matter of preference which type of valve shall be used, though of course the straightway gate valves interpose the least resistance to the flow of steam or water.

When the radiators are but little above the water line in the boiler, gate valves are frequently used on the returns to insure an easy flow of the water.

It seems hardly necessary to point out that a globe valve should be connected in the pipe with its stem horizontal, to avoid the water pocket which occurs when the stem is vertical; nevertheless fitters frequently overlook this point.

Several patterns of radiator valves are shown in Figs. 50, 51, 52, and 53. These valves are of brass or composition, rough body nickel-plated, have wood wheels, and are provided with a union. The angle valves are commonly used on first-floor radiators, those on floors above having offset or corner offset, offset globe, or straightway gate valves, according to the type of radiator and the arrangement of connections to provide for expansion.

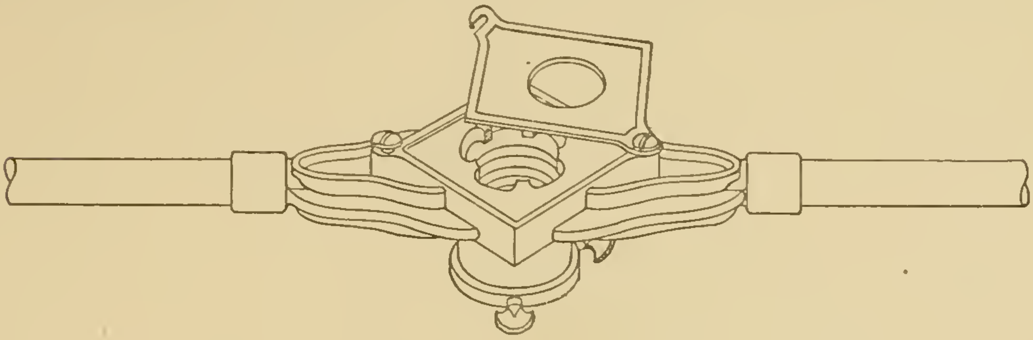


Fig. 63. Stock for Solid Dies.

In public buildings, the wheels are often omitted and lock-shields substituted, the valves being operated by a key.

A *swinging-check* valve is shown in Fig. 54. This type, if properly designed, works the easiest of any, and should be used in preference to other types when radiators are placed but little above the water line in the boiler.

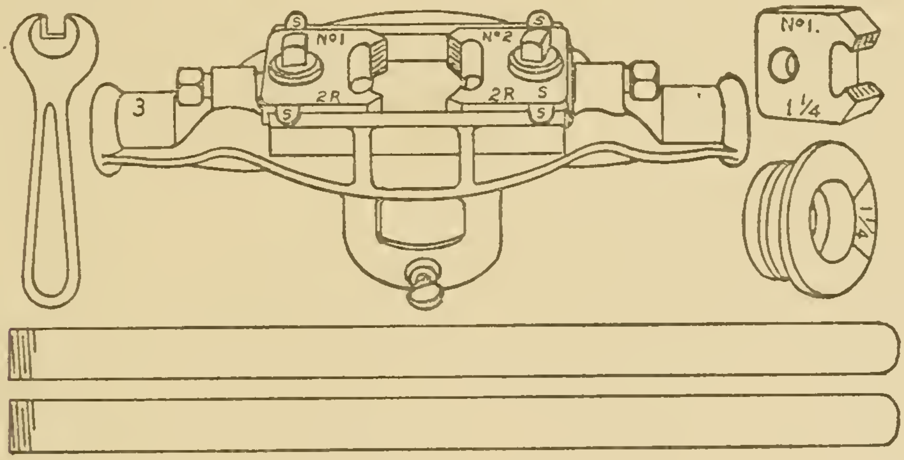


Fig. 64. Adjustable Die and Stock.

Air-Valves. Numerous patterns of air-valves are on the market, some, like Fig. 55, in a general way, being fitted with a union for air-line connections leading to a convenient point of discharge in the basement. Such valves prevent the escape of steam, because of the expansion of the composition plug, which closes the opening when steam comes in contact with it. Air and cold water, however, are permitted to escape.

The general type of air-valve shown in Fig. 56 is frequently used, many modifications of this valve having been manufactured. These valves, as a rule, have no air-line connections, but discharge their air into the rooms: a somewhat objectionable feature. They close when steam enters them; and if water finds its way in, the float is raised and closes the outlet.

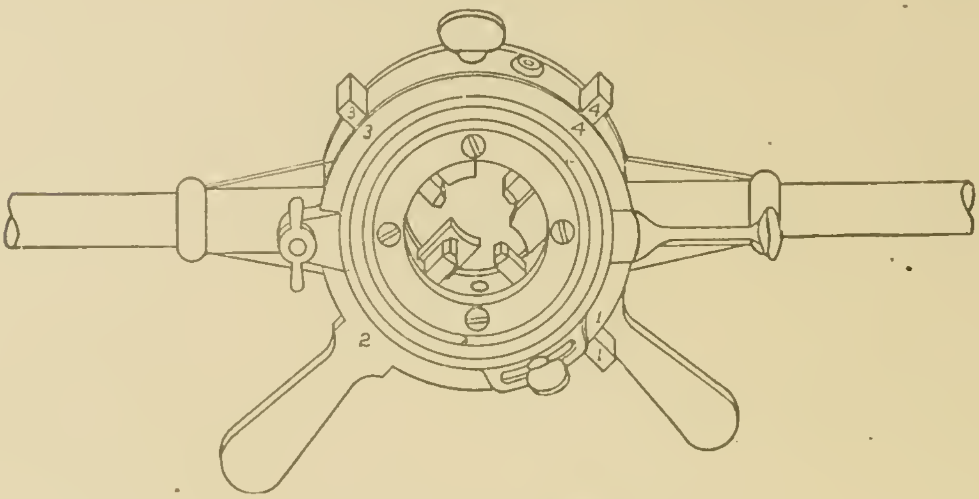


Fig. 65. Adjustable Die and Stock.

Air-valves for direct radiat[illegible] have a very small opening for the discharge of air, scarcely larger than a pin-hole; and while these do very well for small units, they are not satisfactory for large coils or for

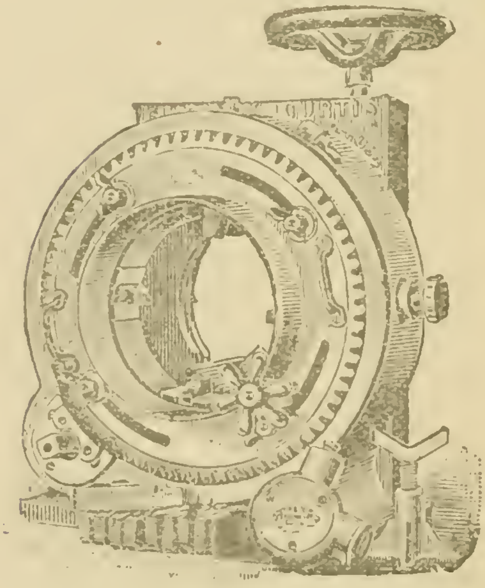


Fig. 66. Hand Power Pipe Machine.

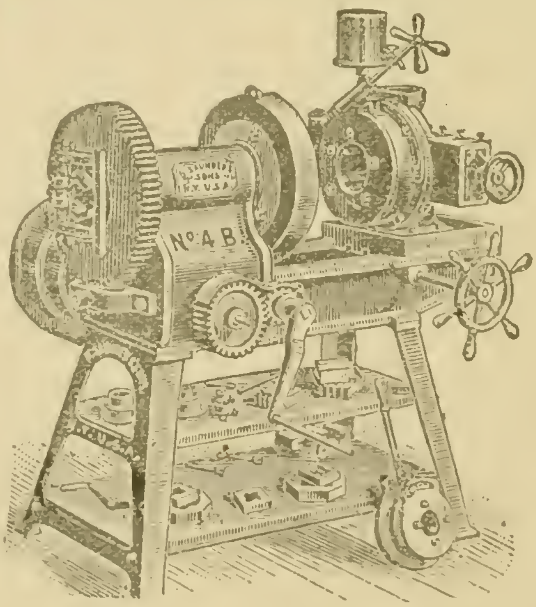


Fig. 67. Belt Power Pipe Machine.

large groups of indirect radiators, because of the excessive time required to relieve them from air. For such heating surfaces, a type of air-valve with a much larger opening should be selected, to provide for venting the radiators or coils more quickly.

Several types of vacuum air-valves have been invented, designed to permit the escape of air from the radiators, but to prevent its reentry. If they remain tight, the steam heating system may be run in mild weather with a pressure below that of the atmosphere, and the radiator kept at a temperature below 200°.

Pipe-Fitting Tools.—Vise and Bench. When a job is started, the first things needed are vise and bench. The latter should be firmly constructed, and rigidly held in place, the vise to be firmly secured to it by through bolts.

On a good-sized piece of work, it is well to have both a *pipe vise* and a *flat-jaw vise*, these being illustrated in Figs. 57 and 58. A heavy cover should be furnished over the screw of the flat-jaw vise, to provide a bearing for bending pipe, the end of which is passed through a ring bolted to the bench.

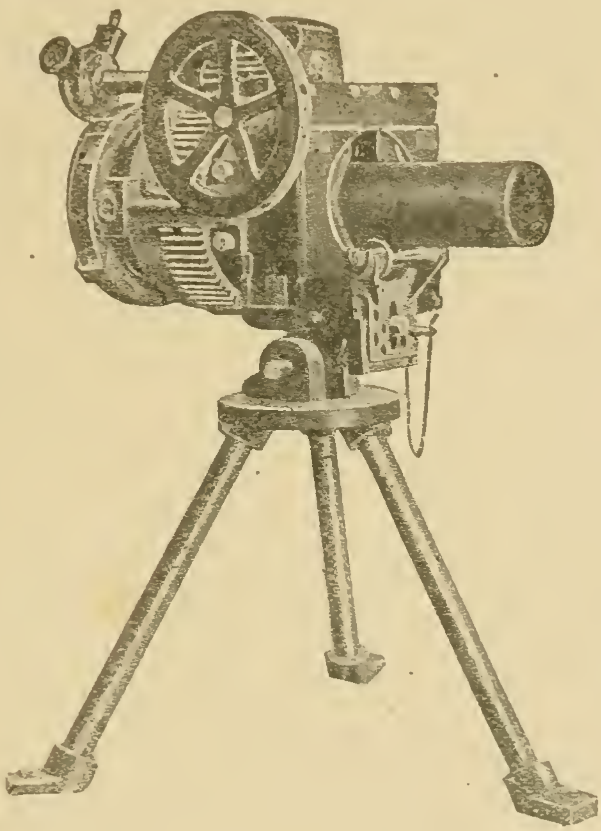


Fig. 68 *a*. Hand Power Pipe Machine.

Fig. 59 illustrates a combination of the two vises shown in Figs. 57 and 58, making a very useful tool.

Pipe Cutters. There are several kinds of pipe cutters on the market, made with one or more cutting wheels held in a frame. All makes of cutters are operated in practically the same way, by forcing the cutting wheels into the pipe by means of a screw handle. One- and three-wheel cutters are shown in Figs. 60 and 61. The one-wheel cutters are made in sizes for $\frac{1}{8}$-inch to 3-inch pipe; and the three-wheel cutters, for $\frac{1}{8}$-inch to 8-inch pipe.

Stocks and Dies. The several forms of dies and stocks on the market may be divided into two classes—the *solid die* and the *adjustable die*. The solid die is shown in Fig. 62, and is used for cutting both right-hand and left-hand threads. The stock in which solid dies are used is shown in Fig. 63. Adjustable dies and stocks are shown in Figs. 64 and 65. These dies may be adjusted to cut a deep or a shallow thread. It is necessary at times to cut such threads, as the fittings made by different manufacturers are not always tapped alike. To make good joints, the threads must make up tight when they are screwed into the fitting.

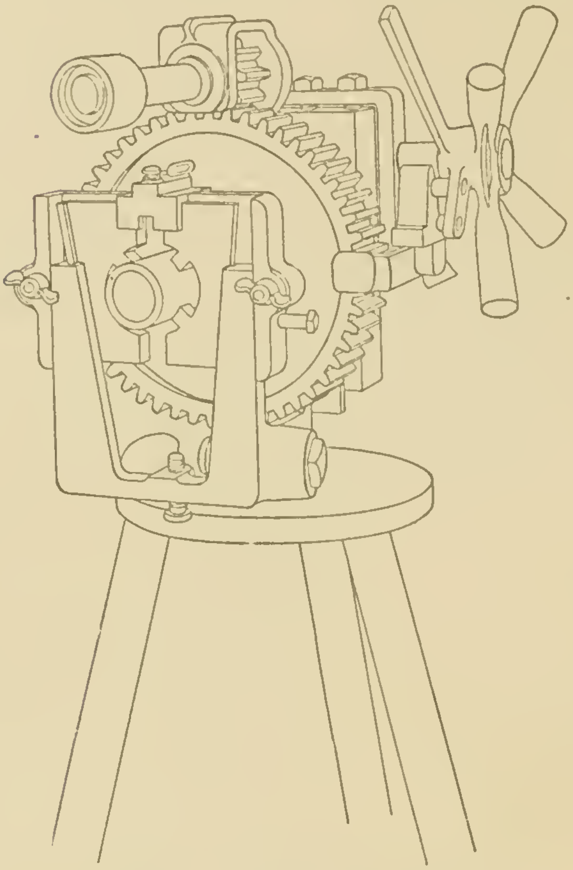


Fig. 68 *b*. Hand Power Pipe Machine.

Table IX shows the approximate distance pipes must be screwed into fittings to make a tight joint.

TABLE IX

Proper Distance to Screw Pipes into Fittings

$\frac{1}{4}$, $\frac{3}{8}$, and $\frac{1}{2}$	inch	pipe	should	be	screwed	into	fittings	approximately	$\frac{3}{8}$	in.
$\frac{3}{4}$	"	"	"	"	"	"	"	"	$\frac{1}{2}$	"
1	"	"	"	"	"	"	"	"	$\frac{11}{16}$	"
$1\frac{1}{4}$ and $1\frac{1}{2}$	"	"	"	"	"	"	"	"	$\frac{5}{8}$	"
2	"	"	"	"	"	"	"	"	$\frac{3}{4}$	"
$2\frac{1}{2}$ and 3	"	"	"	"	"	"	"	"	$\frac{7}{8}$	"
$3\frac{1}{2}$ and 4	"	"	"	"	"	"	"	"	1	"
5 and 6	"	"	"	"	"	"	"	"	$1\frac{1}{8}$	"
7	"	"	"	"	"	"	"	"	$1\frac{1}{4}$	"
8 and 9	"	"	"	"	"	"	"	"	$1\frac{3}{8}$	"
10 and 12	"	"	"	"	"	"	"	"	$1\frac{1}{2}$	"

In all forms of stocks, whether for solid or adjustable dies, a bushing or guide must be used in the stocks to guide the dies straight onto the pipe. It is necessary that the guides for the different sizes of pipe should fit each size of pipe as closely as will allow the guide to revolve on the pipe freely. The guides should fit the stock as tightly as possible, or a crooked thread will very likely be cut.

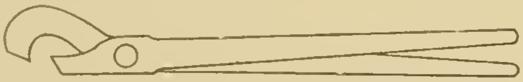


Fig. 69. Pipe Tongs.

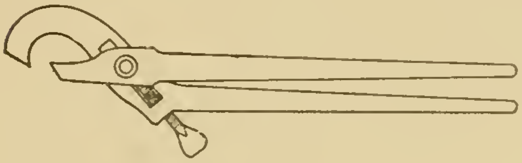


Fig. 70. Adjustable Pipe Tongs.

Plenty of good lard oil or cotton-seed oil should be used when cutting pipe. The dies must be sharp, to make good joints; and when they are changed in the stocks from one size to another, all chips of iron and dirt should be cleaned off the dies and out of the stocks, as a small chip under dies, especially under one of a set of adjustable dies, will either cut a crooked thread or strip it.

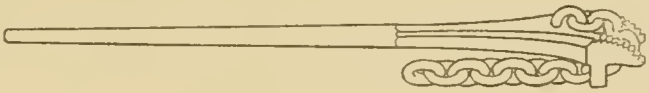


Fig 71. Chain Tongs.

Stocks are made in sizes from $\frac{1}{8}$ inch to 4 inches. The small-size stocks and dies commonly carried in pipe-fitters' kits are made to thread pipe from $\frac{1}{8}$ inch to 1 inch inclusive, right-and left-hand; and a larger size to thread pipe from 1 inch to 2 inches inclusive, right- and left-hand. A larger-size stock is used to cut pipes over 2 inches in diameter.

There are a number of hand-power pipe machines on the market, which are very convenient especially for cutting and threading pipe $2\frac{1}{2}$ inches and over. Several makes are shown in Figs. 66, and 68 *a* and 68 *b*.

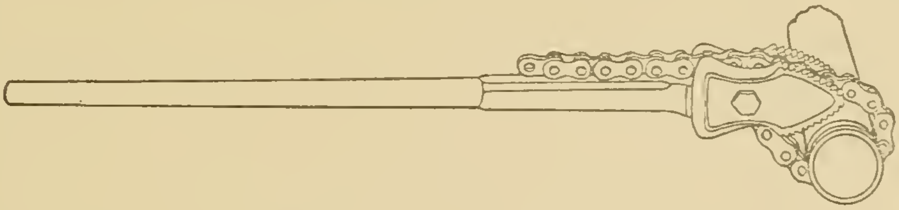


Fig. 72. Chain Tongs.

Pipe Tongs. Plain tongs, like all other tools, must be kept sharp and in good order, to do good work. Many fitters object to tongs because they have to be sharpened very often, and also because they have to carry at least one pair of tongs for each size of pipe; they prefer an adjustable wrench which will fit several different sizes of pipe. There is one advantage in the tongs; that is, they can be worked in places where it would be impossible to use a wrench, such as making up pipe in coils, close corners, etc. Tongs should be made in such a way that when they are on the pipe, the handles will come close enough together to allow them to be gripped in one hand (see Fig. 69).

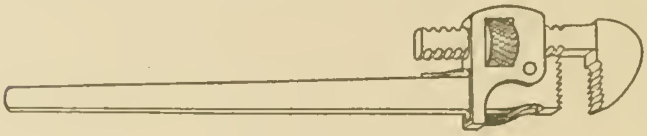


Fig. 73. Pipe Wrench.

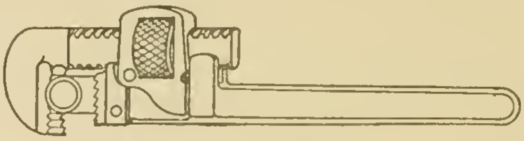


Fig. 74. Pipe Wrench,

Adjustable tongs (Fig. 70) are made to fit several sizes of pipe, the most common sizes used being for $\frac{3}{8}$-inch to 1-inch to 2-inch, and for $2\frac{1}{2}$-inch to 4-inch.

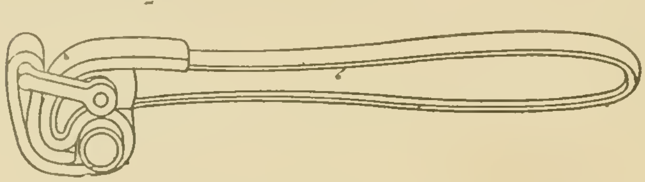


Fig. 75. Wrench for Brass or Nickle-Plated Pipe.

Chain tongs are made in all sizes and in several forms for from 1-inch up to 16-inch pipe. Some makers furnish tongs with the handle and jaws in one piece. Others have the jaws removable. Still others have the jaws so arranged that they can be removed and reversed. See Figs. 71 and 72.

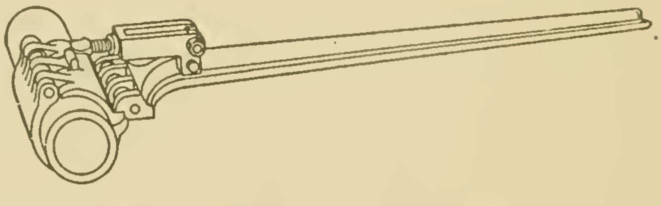


Fig. 76. Wrench for Brass or Nickle-Plated Pipe.

Pipe Wrenches. Several types of adjustable wrenches are shown in Figs. 73 and 74. These wrenches will do good work if used as wrenches on the size pipe they are intended for. Some men who have little regard for tools use on a 2-inch pipe, for example, a wrench which is made to take, say, not over 1-inch pipe, the jaw of the wrench being extended as far as possible, and probably being held by only a few threads of the adjusting screw, a piece of pipe 2 or 3 feet long often being used on the handle of the wrench to

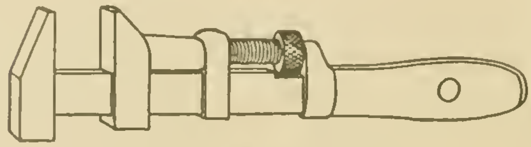


Fig. 77. Monkey Wrench.

increase the leverage. After such usage, the wrench is of little value. At times men will use wrenches in such a way as to make the strain come on the side, with the result that the wrench is badly strained if not broken.

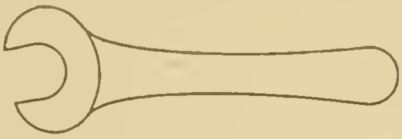


Fig. 78. Open-End Wrench.

The above described wrenches are used on wrought-iron pipe. For brass or nickel-plated pipe, wrenches like those shown in Figs. 75 and 76 should be used; otherwise the pipe will be marred and rendered unfit for use in connection with first-class work.

One of the handiest all-round tools is the *monkey wrench,* shown in Fig. 77. *Open-end* wrenches, illustrated in Figs. 78 and 79, are very handy tools, especially for use on flange fittings. Wrenches for lock-nuts are made about the same as above, only they are larger.

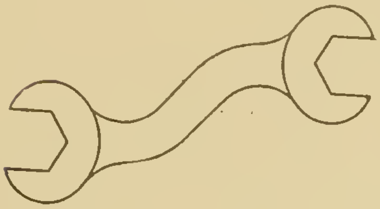


Fig. 79. Open-End Wrench.

The *return-bend wrench* is a very handy tool, and can be made by any good blacksmith. It is used principally on coil work, and is made of heavy bar iron, as shown in Figs. 80 and 81, in which two forms of this type of this wrench are shown.

Another handy tool is what is sometimes called, for want of a better name, a *spud wrench.* This is simply a piece of flat iron about 10 inches long and made to fit the spuds of the unions of different sizes of union radiator valves and elbows (see Fig. 82).

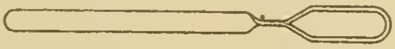


Fig. 80. Return-Bend Wrench.

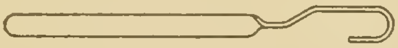


Fig. 81. Return-Bend Wrench.

Pliers. For small work, pliers may be used to advantage. Common and adjustable types are shown in Figs. 83 and 84.

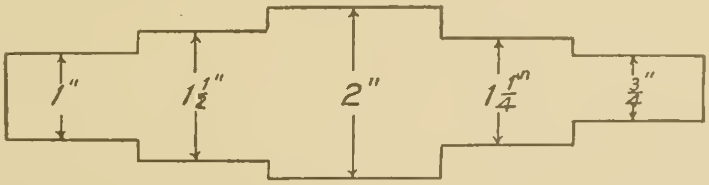


Fig. 82. Spud Wrench.

Drills, Reamers, and Taps. Pipe drills, illustrated in Fig. 85, are made slightly smaller for a given size than the taps illustrated in Fig. 86. A reamer like the one shown in Fig. 87 should be used to start the tap, which should never be hammered in order to start the threads.

Fig. 88 shows a combined drill, reamer, and tap. Fig. 89 shows a pipe reamer for taking the burr from the ends of pipes.

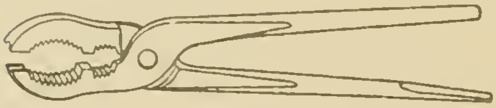


Fig. 83. Common Pliers.

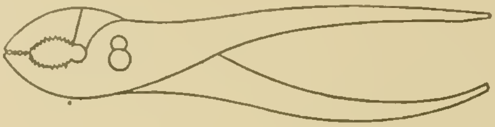


Fig. 84. Adjustable Pliers.

A *ratchet drill* is illustrated in Fig. 90 and a *breast drill* in Fig. 91. Fig. 92 shows a handy tool for drilling pipe flanges which from any cause cannot be drilled in the shop.

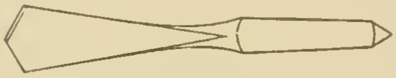


Fig. 85. Pipe Drill.

Figs. 93, 94, 95, and 96 show *cold, cape, diamond point,* and *round-nose* chisels respectively.

A good pattern *pean hammer* is shown in Fig. 97 *a*; and a *brick hammer* is represented by Fig. 97 *b*.

Miscellaneous. Every fitter's kit should contain inside and outside *calipers*; a good set of *bits* ¼-inch to 1-inch; *bit stock*; *augers* 1¼-inch to 2-inch; *saws*; *files*; *plumb-bob*; *gimlet*; *lamp*; *oil can*; *steel square*; *tape measure*; etc.

HOT-WATER HEATING

Heaters. Hot-water heaters—or "boilers," as they are sometimes miscalled—are so nearly like the cast-iron steam boilers previously illustrated, that it is unnecessary further to describe them here.

Some makers use the same patterns for both steam boilers and hot-water heaters, while others use a higher boiler for steam, giving more space above the water line.

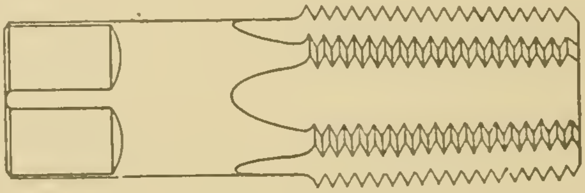
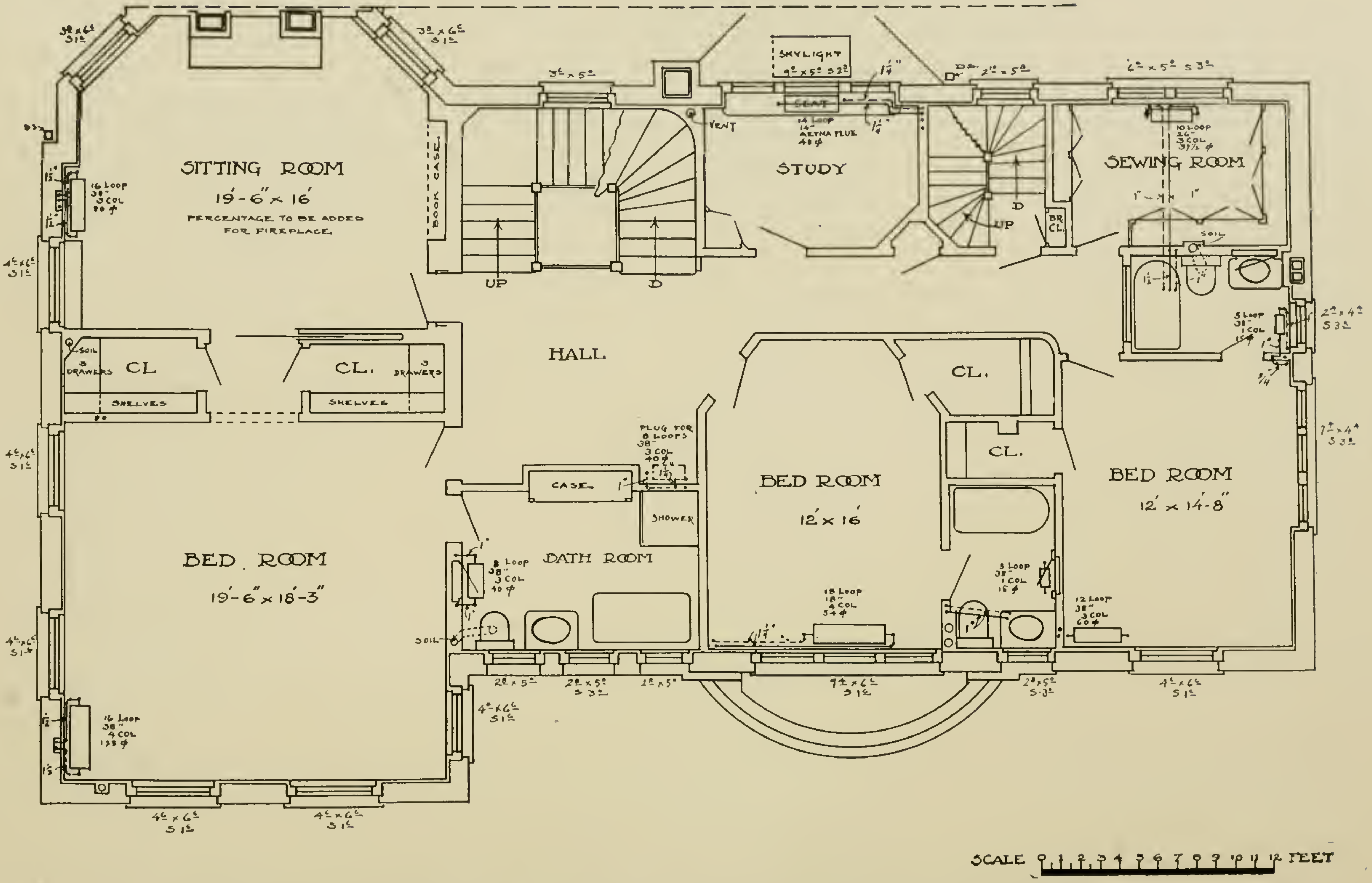


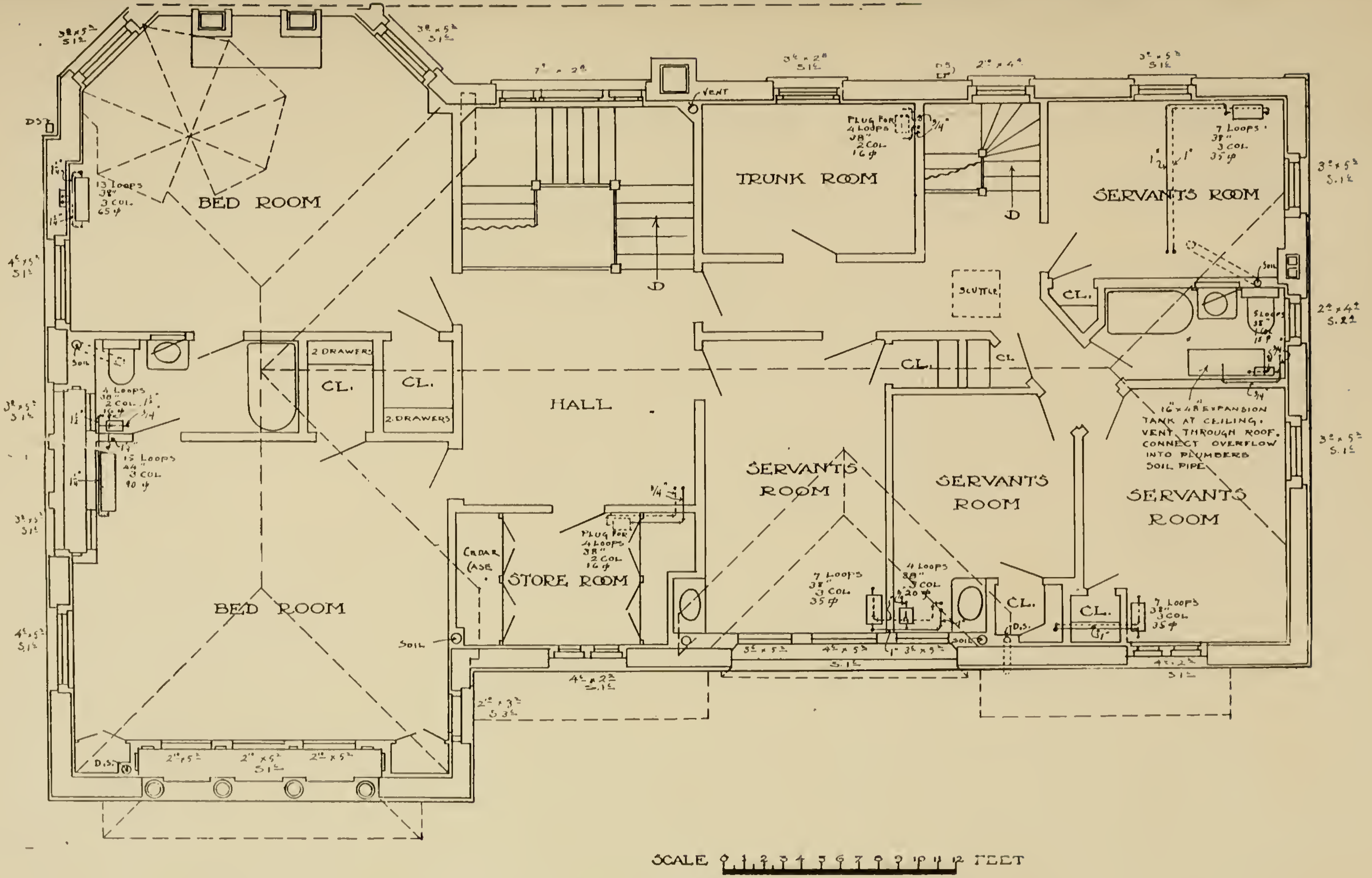
Fig. 86. Pipe Tap.

Practically the same rules should be followed in selecting a hot-water heater as those laid down for steam boilers. Although a hot-water heater is a trifle more efficient than a steam boiler—that is, more of the heat in the coal is transferred to the water, owing to the temperature of the latter being 40 degrees or more lower than in a steam boiler—nevertheless, practically the



SECOND-STORY PLAN OF RESIDENCE OF MRS. JAMES H. BARNARD, SHOWING LAYOUT OF HOT-WATER HEATING PLANT

W. Carbys Zimmerman, Architect, Chicago, Ill. For Basement and First-Story Plans, See Page 170.



THIRD-STORY PLAN OF RESIDENCE OF MRS. JAMES H. BARNARD, SHOWING LAYOUT OF HOT-WATER HEATING PLANT

W. Carbys Zimmerman, Architect, Chicago, Ill.

same size of hot-water heater or steam boiler is required to heat a given space.

It is well to equip the heater with a regulator, of which a number of good ones are manufactured, in order to control the drafts by variations in the temperature of the water, the regulator being set to maintain any desired temperature in the flow pipe.

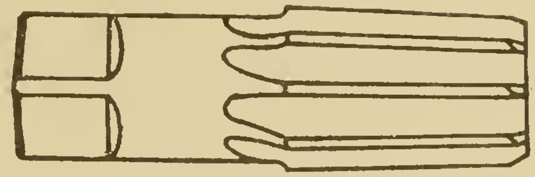


Fig. 87. Reamer.

Capacity of Heaters. Hot-water heater capacities are based, as a rule, on an average water temperature of 160° in the radiators, when placed in rooms to be kept at 70° F. If the *closed-tank system* is used, the radiator temperatures may be 220° to 230° or more; hence, if any attention is to be given to the manufacturers' heater rating, the radiation must be reduced to the equivalent radiation in heat-emitting capacity of radiators at 160°.

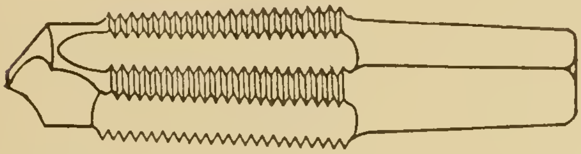


Fig. 88. Combined Drill, Reamer and Tap.

This is very easily computed, since the heat given off by a radiator is proportional to the difference in temperature between the water in the radiator and the air surrounding it. This, in the first case, is 160° less 70°, or 90°; and in the other case, say, 225° less 70°, or 155°; that is, one foot of radiating surface at 225° will give off $\frac{155}{90}$ of the heat given off at 160°; therefore, a job with 900 square feet, for example, at 225° would be equivalent in heating power to $\frac{155}{90} \times 900 = 1550$ square feet at 160°, and a boiler with the higher rating would be required

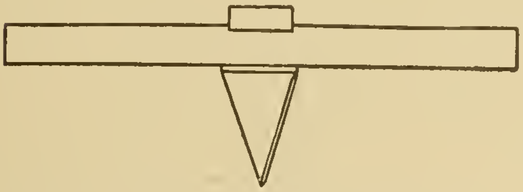


Fig. 89. Pipe Reamer for Taking the Burr from Ends of Pipe.

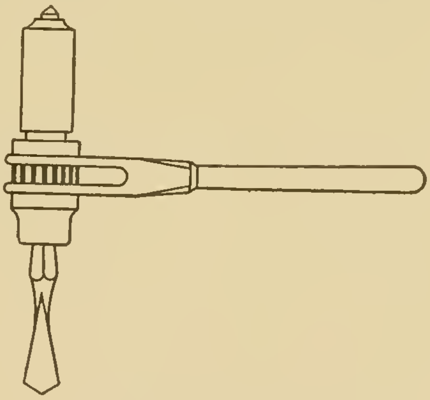


Fig. 90. Ratchet Drill.

It is always well to check the boiler rating as explained under "Steam Heating," except that in hot-water heating only 150 heat units are allowed per hour per square foot of radiating surface.

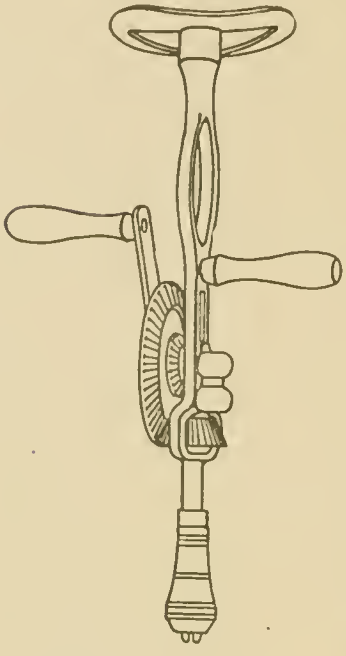


Fig 91. Breast Drill.

Of the heat given off by the coal, it is safe to assume that 8000 heat units per pound are transferred to the water in the heater. Suppose there are 900 square feet of radiation on the job. Add $\frac{1}{3}$ to cover the loss of heat from pipes; total = 1200 square feet. Assume that in coldest weather 5 pounds of coal are burned per hour on each square foot of grate; that is, 5 × 8000 = 40,000 heat units are transferred to the water in the heater. The heat given off per hour by the radiators and pipes is 1200 × 150 = 180,000 heat units. This, divided by 40,000, the heat utilized per square foot of grate, equals $4\frac{1}{2}$ square feet of grate required.

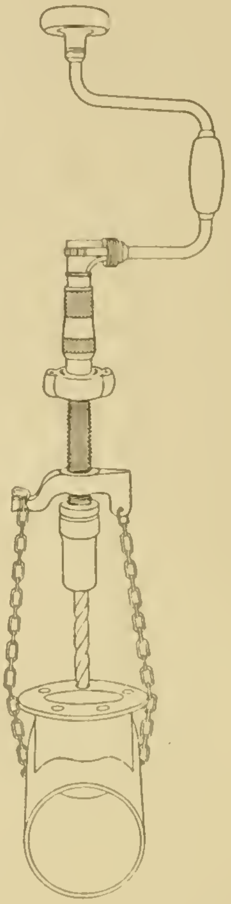


Fig. 92. Tool for Drilling Pipe Flanges.

Some judgment is necessary in assuming the rate of combustion; but this varies from about 3 pounds per square foot of grate per hour in small heaters, to 7 or 8 in larger ones, operated by a regular attendant.

HOT-WATER RADIATORS AND VALVES

Hot-water radiators have top and bottom nipple connections, as shown in Fig. 31, Part II (Heating and Ventilation). A hot-water radiator may be used for steam, but a steam radiator cannot be used for hot water. The valve may be placed at the top or the bottom—it

Fig. 93. Cold Chisel.

matters little which; it is, however, more convenient, though more unsightly, at the top. The circulation will be practically as good when the valve is located at the bottom. One valve is all that is necessary, and this may best be of the quick-opening pattern, a partial turn being all that is necessary to open or close it (see Figs. 44 and 45, Part II, Heating and Ventilation).

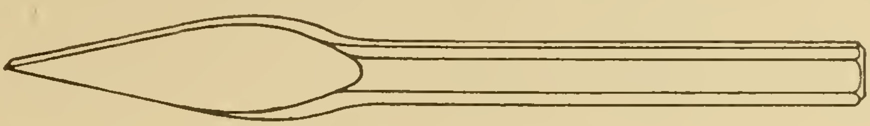


Fig. 94. Cape Chisel.

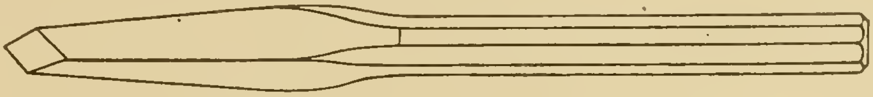


Fig. 95. Diamond-Point Chisel.

A union elbow is generally connected with the return end of a radiator (see Fig. 46, Part II, Heating and Ventilation).

Key-pattern air-valves are more frequently adopted in hot-water heating than are any types of automatic valves. They do not have to be operated often; hence the popularity of the simple and reliable air-cocks like those shown by Fig. 98.

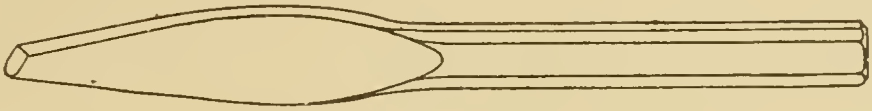


Fig. 96. Round-Nose Chisel.

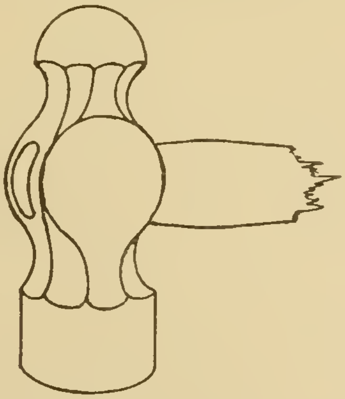


Fig. 97 *a*. Pean Hammer.

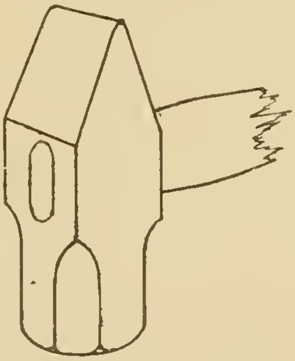


Fig. 97 *b*. Brick Hammer.

Direct-indirect hot-water radiators are seldom used, owing to the danger from freezing in case they are thoughtlessly shut off.

Indirect radiators should be of a deep pattern—say, 10 to 12 inches, or even more for use with outdoor air in a severe climate. These radiators give off far less heat per square foot than is emitted by steam radiators; hence they should be deeper, to bring the air up to proper temperature.

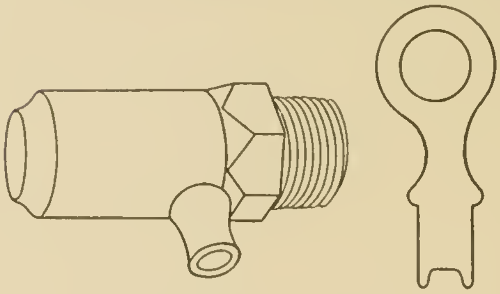


Fig. 98. Air Cock.

HOT=WATER PIPING

Heater Connections. Where only one heater is used, the connections are practically the same as for steam heating, except that no check-valves are used.

Where two boilers are to be connected and arranged to be run independently or together, valves must be inserted somewhat as shown by the plan view represented in Fig. 99. It is important that safety-valves be used with this arrangement, as, in case one boiler is shut down and then fired up without opening the stop-valves, the pressure due to the expanding water will burst the heater.

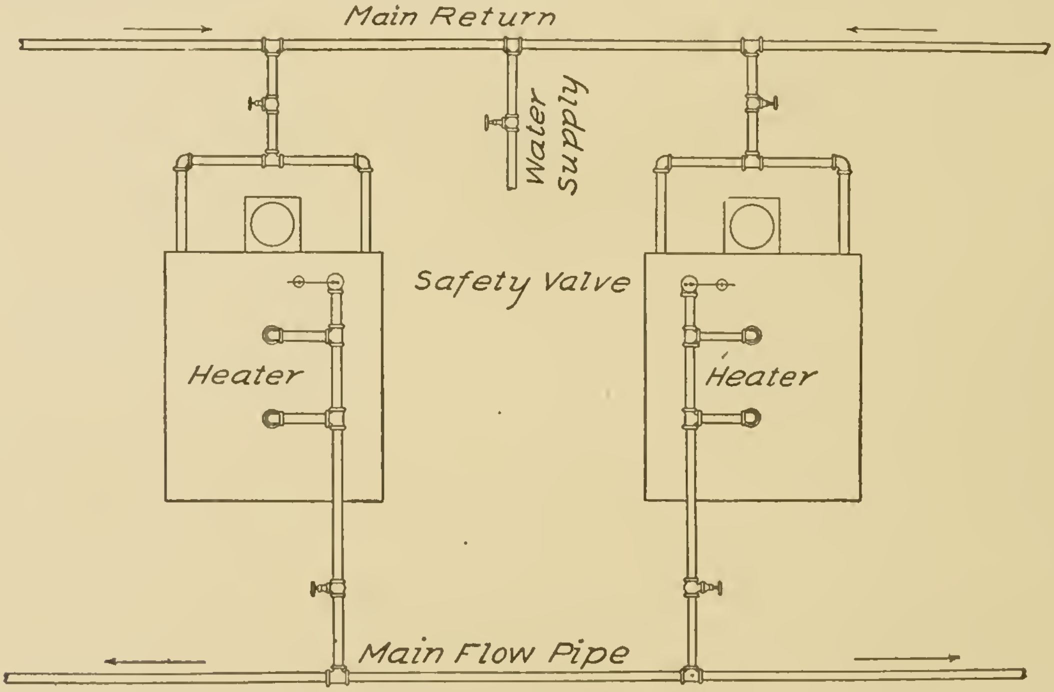


Fig. 99. Arrangement of Valves for Two Boilers which are to Run Independently or Together.

Single-Main System. The single-main system, arranged somewhat like the circuit system in steam heating, is sometimes employed for hot-water heating. Fig. 100 shows the arrangement of this system. The supply branches are taken from the top of the main, where the water is hottest; and the returns are connected at the side, the cooler water passing along the lower portion of the pipe back to the heater. On systems of considerable size, this arrangement of piping causes the water in the supply main to cool more rapidly as the distance from the heater increases than in systems where the supply and return water are kept separate.

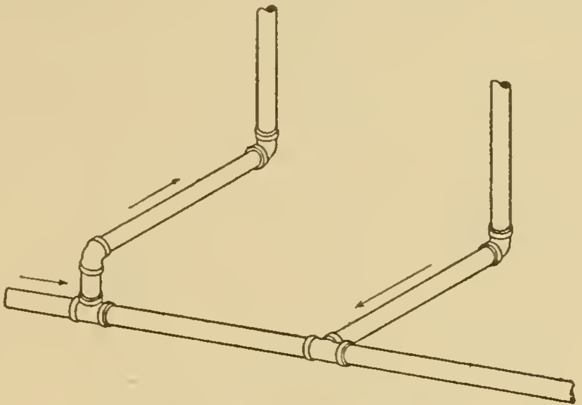


Fig. 100. Single Main System.

Two-Pipe Up-Feed System. With the two-pipe up-feed system, the pipes should be pitched up from the boiler 1 inch in 10 feet, if possible. Pockets in which air can collect must be avoided, as air will cut off the flow as much as a solid substance in the pipe would do.

In the basement, the branches near the boiler should be taken from the side of the flow main, in order to favor the branches farther away, which should be taken from the top of the main. First-floor radiators should be given the preference, as to ease of flow in their connections, over riser connections with the floors above. If possible, feed the last first-floor radiator on a line before branching to riser. Fig. 101 illustrates the above points.

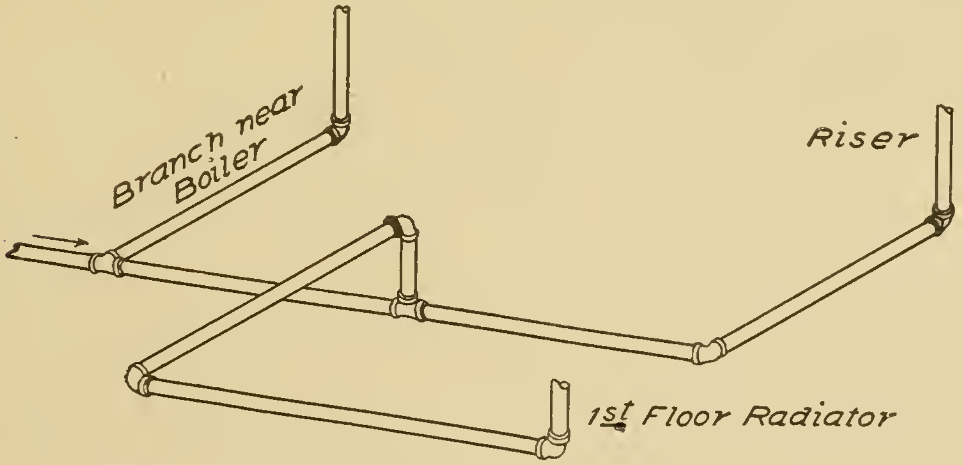


Fig. 101. Two-Pipe Up-Feed System.

Keep the mains near the ends of long runs ample in size, even if somewhat larger than stated in the table, if runs are long and crooked. No chances should be taken in regard to insuring the proper circulation of water in the system. Use no horizontal pipe smaller than 1¼-inch..

Return mains pitch in the same direction as the flow pipes, and are generally paired with them, the connections being made on the side as shown in Fig. 102, or at an angle of 45 degrees.

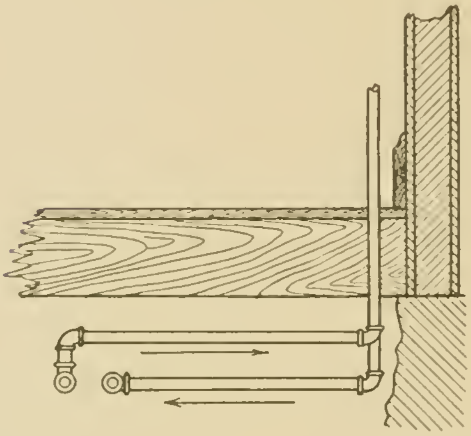


Fig. 102. Connections for Return Mains.

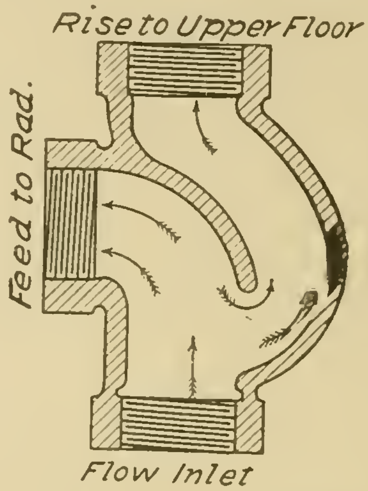


Fig. 103. Distributing Fitting.

The risers should be arranged to favor the radiators on the lower floors, since the water tends to rise and pass by the lower radiators. Distributing fittings, as shown in Fig. 103, are often used for this purpose, or the pipes may be arranged as shown in Fig. 104. Some labor is saved by the use of the special fittings described.

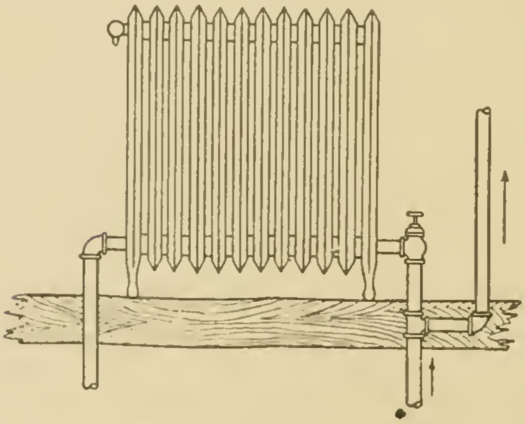


Fig. 104. Arrangement of Pipes.

Overhead-Feed System. Where attic space is available, the overhead-feed system presents certain advantages over the two-pipe up-feed method of piping. In residences, single risers are used, these serving for both supply and return, the water entering the top of the radiator and flowing back into the same riser from the lower opening in the radiator. No air-valves are necessary, all air passing up the risers and out through the vent, on the expansion tank. The overhead mains are connected with a rising main large enough to supply all the surface; these mains may be run around the building near the walls, as in the one-pipe steam circuit system; or may be carried down the middle of the building, with long branches extending to the risers near the walls, it being assumed that the radiators will be located near the exposed parts of the building.

The mains and branches should pitch down toward the risers, permitting the air to escape freely to the expansion tank (see Fig. 105).

Special care should be used in hot-water heating, to secure an easy flow. The ends of the pipes should be reamed, and long-turn fittings used for first-class work, although, if the piping is generously proportioned, standard fittings will answer. A hot-water thermometer should always be placed on the boiler or near it, in the flow-main.

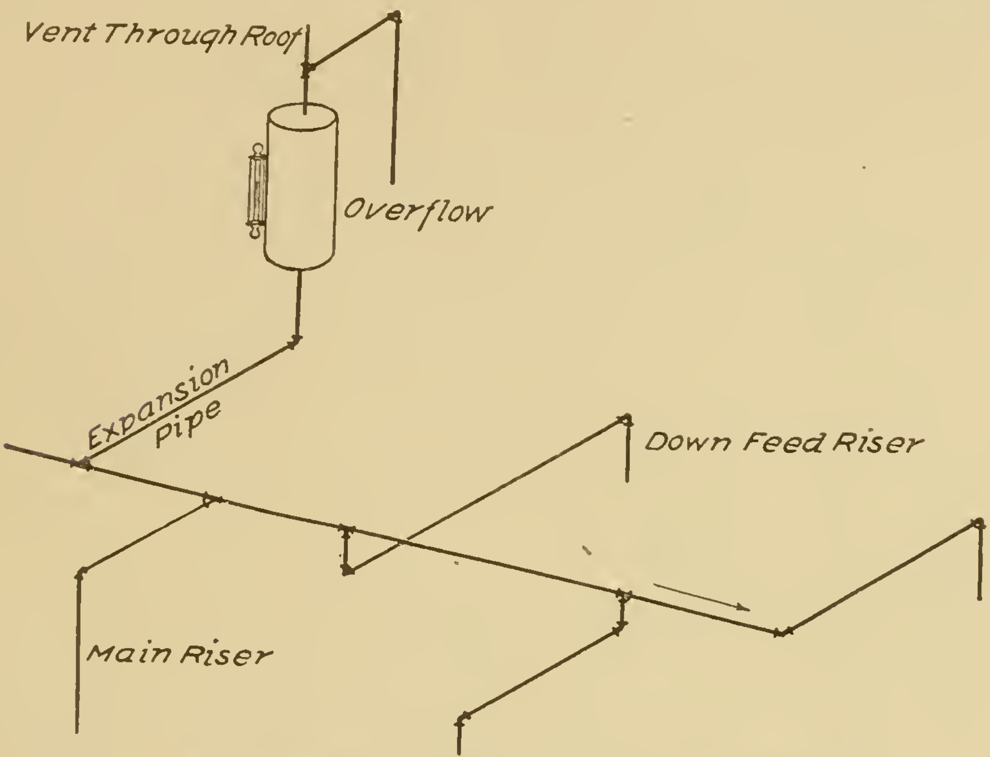


Fig. 105. Showing the Mains and Branches Pitched Down Towards the Risers.

Radiator Connections. For direct radiators, the connections are commonly 1-inch for sizes up to 40 square feet; 1¼-inch, for sizes of 72 square feet; 1½-inch to 2-inch for sizes larger than 72 square feet. On floors above the first, the connections may be made smaller if the horizontal runs are short, the sizes to conform to table.

Expansion-Tank Connections. About the simplest arrangement of expansion-tank connections is shown in Fig. 106. The expansion pipe is commonly connected with a return line in the basement, there being less likelihood of the water boiling over in case of a hot fire with this arrangement than when the expansion pipe is merely an extension of a supply riser. There must be no valve on this pipe, as its closure would almost certainly result in a bursting of some part of the system.

Great pains must be taken to guard against the freezing of the expansion pipe. If there is any danger whatever, a circulating pipe should be added, as shown, this pipe being connected with one of the flow-pipes or supply risers, to insure a continuous circulation.

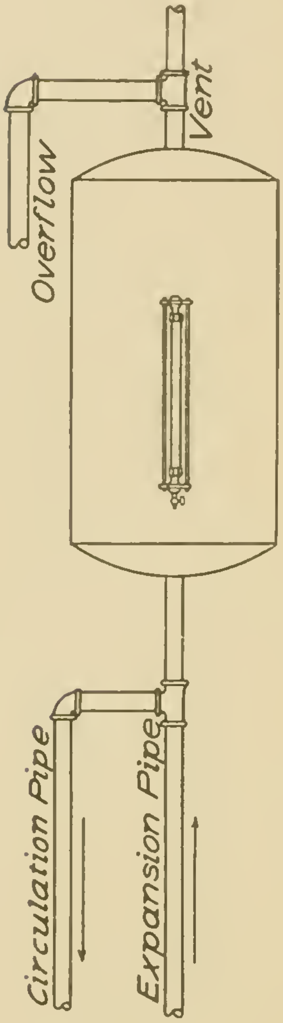


Fig. 106. Expansion Tank Connections.

Open-Tank versus Pressure System. The open-tank system, although having its disadvantages, is generally to be preferred to the pressure or closed-tank system. With the open-tank system, the water cannot get much above 212° at the heater, without boiling in the expansion tank and blowing part of the water out of the system, causing, meanwhile, objectionable noises in the system. On the other hand, the open expansion tank into which the water can freely expand when heated is the best possible safety device to prevent overpressure.

With the closed-tank system, a safety-valve is used. If it operates properly, well and good; otherwise an element of danger is introduced, and, in case an excessive pressure is developed, the heater becomes far more dangerous than a steam boiler, owing to the much greater volume of water in the system.

With this system, two safety-valves with non-corrosive seats should be used, unless some well-tested device of demonstrated merit designed especially for this purpose is adopted.

The advantage of the closed-tank system is that smaller radiators may be used, since they can be heated as hot with water under pressure as they would be if heated with steam.

When full street pressure is applied to a system, and no expansion tank is used, the radiators are subjected to an unnecessary strain; and in case of rupture in any part of the system, much greater damage results than would be the case with an open-tank system.

System of Forced Circulation. In extensive systems the water is kept in circulation by pumps, which are capable of producing a much higher velocity in the pipes than could be secured by gravity. This system is used principally in connection with power plants, the water being heated in tubular heaters, by means of the exhaust steam from the engines. Much smaller supply mains may be used in this system than with steam heating, because of the greater capacity of water for carrying heat. On the other hand steam returns are smaller.

Table X gives the capacities of expansion tanks:

TABLE X

Radiation Capacities of Expansion Tanks

Capacity of Tank	Direct Radiating Surface to which Tank is Adapted
5 gallons	200 sq. ft.
10 "	450 " "
15 "	700 " "
20 "	1000 " "
30 "	1400 " "
40 "	1900 " "
50 "	2400 " "
60 "	2900 " "

COMPUTING RADIATION

Computing Direct Radiation. The process of computing hot-water radiating surface is precisely the same as that explained for ascertaining the amount of steam radiation required for a given case, with this important exception: the hot-water radiators give off only about $\frac{3}{5}$ as much heat per square foot as is emitted by a steam radiator; hence calculations must be based on an allowance of 150 heat units per square foot of direct radiating surface per hour, instead of 250 heat units used in connection with steam-heating work.

It has been stated that direct-indirect hot-water radiators are rarely used. In case, however, it is desired to compute the amount of this class of radiation for a given service, proceed as explained for steam heating, but allow only $\frac{3}{5}$ as much heat emitted per square foot as that given off by steam radiators.

Computing Indirect Radiation. With indirect hot-water radiation in connection with the open-tank system, the radiators must be deeper than for steam heating, in order properly to heat the air.

The greater depth retards the flow of air; and since the water is at a much lower temperature than steam, the heating capacity of indirect extended-surface hot-water radiators should be taken at not far from 300 heat units per square foot per hour, as against 400 or more heat units for indirect steam radiation.

To compute the amount of radiation required, proceed as explained for indirect steam heating; that is, compute the amount of direct radiation as pointed out under the preceding heading, then add not less than 60 per cent to this amount, to ascertain the indirect radiating surface required.

This method, though perhaps crude, has the advantages of being simple and of affording a check on the work, since one soon knows by experience about what the ratio should be to heat a room of given size by direct radiation. For example, take a room with 3000 cubic feet, to heat which the ratio for direct radiation should be, say, 1 square foot to 30 cubic feet, giving a 100-square foot radiator. Adding 60 per cent for indirect radiation, gives 160 square feet, or a ratio of 1 square foot to a little less than 20 cubic feet of space.

Indirect hot-water radiators with extended pins or ribs will, with the open-tank system, give off not far from 250 to 300 heat units per hour per square foot of extended surface.

DUCTS AND FLUES

Areas of Ducts and Flues. When indirect radiation is installed primarily for heating, ventilation being a secondary consideration, it is desirable to make the flues somewhat smaller in proportion to the heating surface than is done with steam heating. If the flues are made too large, the flow through the radiators will be too rapid, and the air will not get hot enough. It costs far more in fuel to heat with a large volume of moderately warmed air than with a smaller volume of hotter air.

Duct and flue proportions for hot-water heating should be approximately as follows:—Cold-air ducts, ¾ to 1 sq. in. per sq. ft. of indirect radiating surface; first-floor flues, 1¼ to 1½ sq. in. per sq. ft.; second-floor flues, 1 to 1¼ sq. in. per sq. ft.; third-floor flues and above, ¾ to 1 sq. in. per sq. ft. of surface.

The backs and sides of flues in exposed walls should be covered with non-conducting material.

Flue Velocities. The flue velocities will be somewhat lower than with steam heating, because of the lower temperature of the air. Reasonable allowance would be 250, 350, 400, and 450 feet per minute for the first, second, third; and fourth floors respectively.

Heating Water. The size of heater or steam coil necessary to heat water may be very readily determined on the heat-unit basis, if one knows the volume of water to be heated, the number of degrees its temperature is to be raised, and the time during which the heating must be done.

For example, what size of heater would be required to heat 300 gallons of water in 6 hours from 60° to 160°?

In one hour 50 gals. would be heated 100° F.; and since one gal. weighs $8\frac{1}{3}$ lbs., $50 \times 8\frac{1}{3} \times 100 = 41{,}667$ heat units would be required.

Small heaters may be counted on to transmit to the water about 7000 heat units per pound of coal burned. The rate of combustion should be assumed to be from 3 to 6 pounds per square foot of grate per hour, according to the amount of attendance it is convenient to give.

With a 4-pound rate, 28,000 heat units would be furnished per square foot of grate surface per hour for heating the water. Therefore the heat units per hour necessary to raise the temperature of the water—*viz.*, 41,667—divided by 28,000, gives the number of square feet of grate surface required, which is equal to about $1\frac{1}{2}$ corresponding to a diameter of $16\frac{1}{2}$ inches.

To determine the size of steam boiler and coil required to heat a large volume of water in a tank, proceed as follows: Take, for example, a 24,000-gallon tank, the water in which is to be heated from 45° to 75° in 10 hours. Now 24,000 gals. $\times\ 8\frac{1}{3}$ pounds $\times$ 30° rise in temperature = 6,000,000 heat units, or 600,000 heat units per hour.

Assuming 8000 heat units to be utilized per pound of coal burned at, say, a $7\frac{1}{2}$-pound rate, one square foot of grate will supply 60,000 heat units per hour; hence, 10 square feet of grate surface will be required.

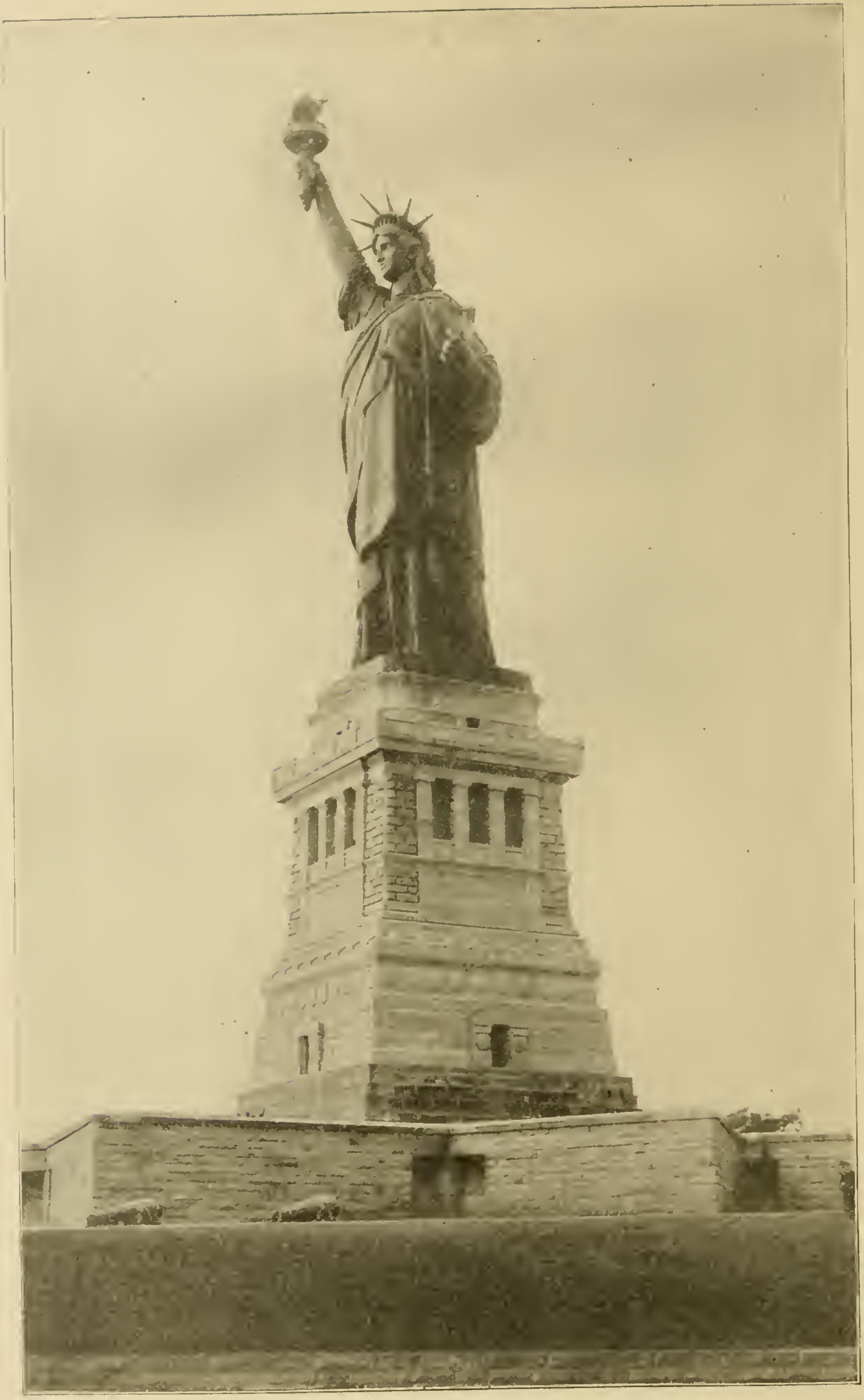
There will, however, be a certain loss of heat from the tank by radiation, conduction, and evaporation; therefore, not less than, say, 12 square feet should be used in order to provide a reasonable margin.

As to the size of steam coil required, a square foot of pipe surface surrounded by circulating water may be assumed to transmit to the water not far from 100 heat units per degree difference in temperature between the steam and the water in contact with the pipe.

Assume the steam temperature to be 230°, corresponding to a trifle more than 5 pounds gauge pressure. When the water in the tank is cold, the condensation of steam in the coil will be much more rapid than when the surrounding water becomes warmer. The average temperature of the water during the 10-hour period is 60°; but the water leaving the pipe and in contact with the upper half of its surface is at a considerably higher temperature than the main body of water in the tank; therefore, with natural circulation, it is well to make ample allowance for the effect of this skin of warm water surrounding the steam coils, and to assume that they will not give off more than $\frac{2}{3}$ as much heat as that corresponding to the difference in temperature between the steam and the water in the tank, based on 100 heat units per degree difference as stated above.

In other words, allow only $66\frac{2}{3}$—or, in round numbers, 70—heat units per hour per degree difference in temperature between the steam and the water in the tank.

If the difference in temperature is $230° - 70° = 160°$, on the basis stated, one square foot of coil would give off $70 \times 160 = 11{,}200$ heat units per square foot per hour; and since 600,000 heat units must be supplied to the water, a 53-square foot coil or slightly larger would be required, equal to about 122 ft. of $1\frac{1}{4}$-inch pipe.



LIBERTY ENLIGHTENING THE WORLD

Colossal Statue by Bartholdi, Erected on Bedloe's Island, New York Harbor. A Gift of the French People to the American Nation. Dedicated in 1886. Total Height, 305 Feet. Height of Statue without Pedestal, 151 Feet. The Statue Consists of a Trusswork of Iron Beams Enveloped in a Sheathing of Copper Plates Hammered into Shape. Over 200 Tons of Metal was Used in the Construction. The Pedestal, Designed by the Late Richard H. Hunt, was Paid for Largely by Popular Subscription in the United States.

ELECTRIC WIRING

METHODS OF WIRING

The different methods of wiring which are now approved by the National Board of Fire Underwriters, may be classified under four general heads, as follows:

1. Wires Run Concealed in Conduits.
2. Wires Run in Moulding.
3. Concealed Knob and Tube Wiring.
4. Wires Run Exposed on Insulators.

WIRES RUN CONCEALED IN CONDUITS

Under this general head, will be included the following:

(*a*) Wires run in rigid conduits.
(*b*) Wires run in flexible metal conduits.
(*c*) Armored cable.

Wires Run in Rigid Conduit. The form of rigid metal conduit now used almost exclusively, consists of plain iron gaspipe the interior surface of which has been prepared by removing the scale and by removing the irregularities, and which is then coated with flexible enamel. The outside of the pipe is given a thin coat of enamel in some cases, and, in other cases, is galvanized. Fig. 1 shows one make of enameled (unlined) conduit.

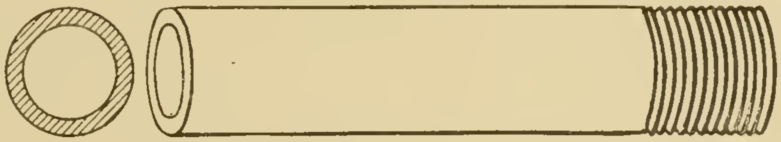


Fig. 1. Rigid Enameled Conduit, Unlined.
Courtesy of American Conduit Mfg. Co., Pittsburg, Pa.

Another form of rigid conduit is that known as the *armored conduit,* which consists of iron pipe with an interior lining of paper impregnated with asphaltum or similar compound. This latter form of conduit is now rapidly going out of use, owing to the unlined pipe being cheaper and easier to install, and owing also to improved methods of protecting the iron pipe from corrosion, and to the introduction of additional braid on the conductors, which partly compensates for the pipe being unlined. The introduction of improved devices—such as outlet insulators, for protecting the conductors from the sharp edges of the pipe, at outlets, cut-out cabinets, etc.—also decreases the necessity of the additional protection afforded by the interior paper lining.

Rigid conduits are made in gaspipe sizes, from one-half inch to three inches in diameter. The following table gives the various data relating to rigid, enameled (unlined) conduit:

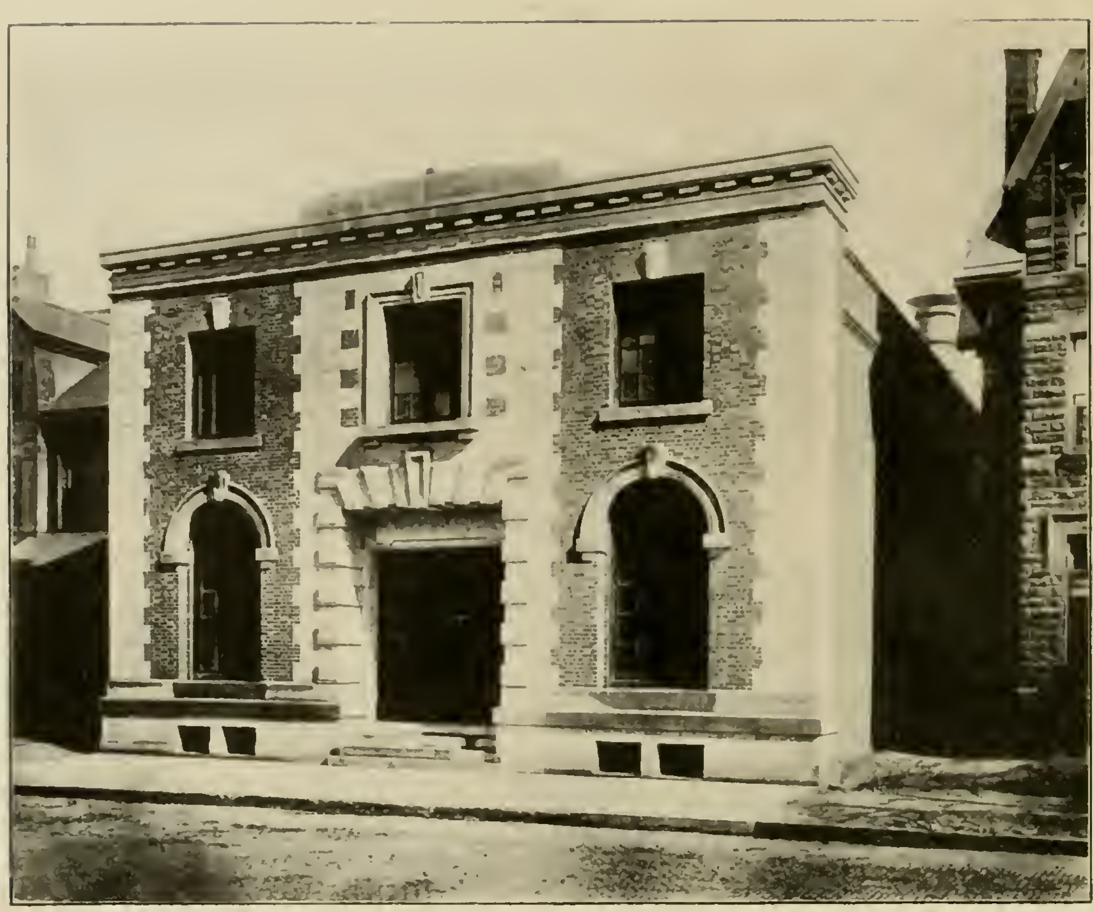
TABLE I
Rigid, Enameled Conduit—Sizes, Dimensions, Etc.

Standard Pipe Size	Thickness	Nominal Weight per 100 Feet	Number of Threads per Inch of Screw	Actual Outside Diameter. Inches	Nominal Inside Diameter. Inches
½	.109	84	14	.84	.62
¾	.113	112	14	1.05	.82
1	.134	167	11½	1.31	1.04
1¼	.140	224	11½	1.66	1.38
1½	.145	268	11½	1.90	1.61
2	.154	361	11½	2.37	2.06
2½	.204	574	8	2.87	2.46
3	.217	754	8	3.50	3.06

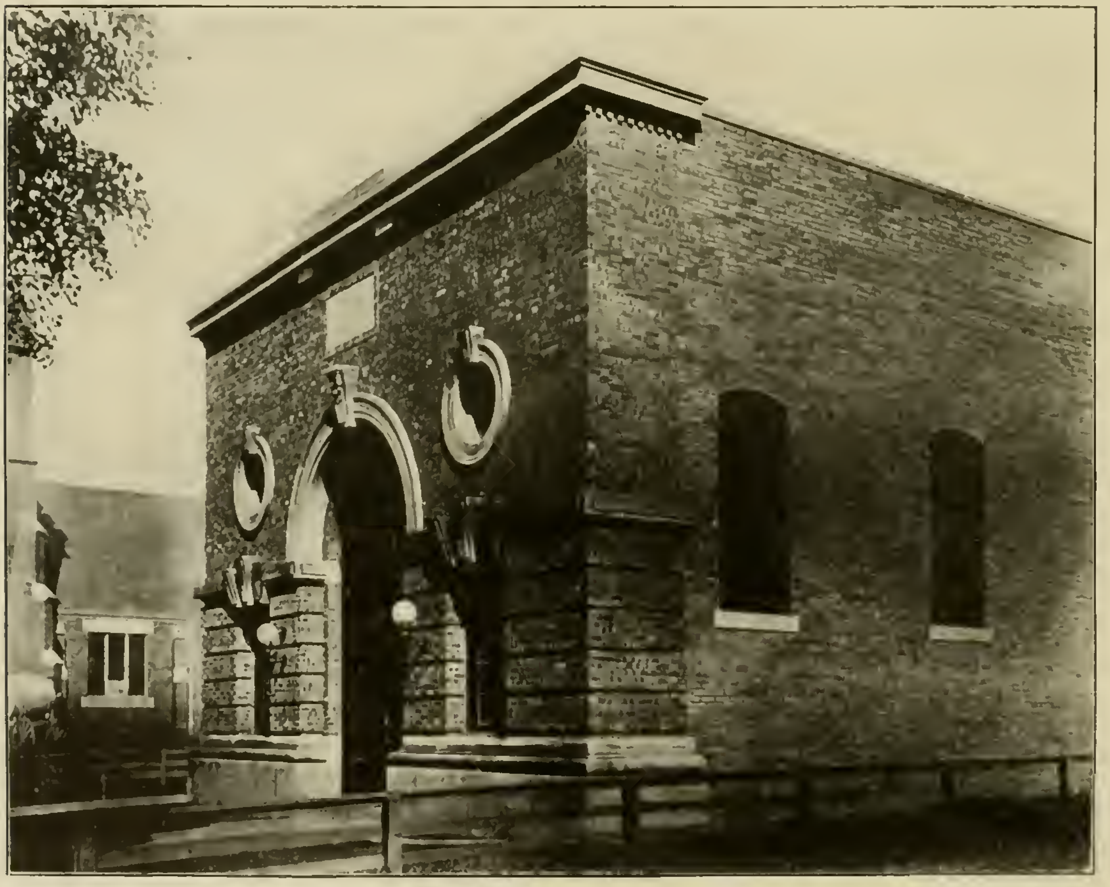
Tables II, III, and IV give the various sizes of conductors that may be installed in these conduits. Caution must be exercised in

TABLE II
Single Wire in Conduit

Size Wire, B. & S. G.	Loricated Conduit, Unlined; D. B. Wire
No. 14-4	½ inch
" 2	¾ "
" 1	¾ "
" 0	¾ inch or 1 "
" 00	1 "
" 000	1 "
" 0000	1 "
250,000 C. M.	1¼ "
300,000 C. M.	1¼ "
350,000 C. M.	1¼ "
400,000 C. M.	1¼ " or 1½ "
450,000 C. M.	1½ "
500,000 C. M.	1½ "
600,000 C. M.	1½ " or 2 "
700,000 C. M.	2 "
800,000 C. M.	2 "
900,000 C. M.	2 "
1,000,000 C. M.	2 " or 2½ "
1,500,000 C. M.	2½ "
1,700,000 C. M.	3 "
2,000,000 C. M.	3 "



Dodge Street Substation



Doan Street Substation

SUBSTATIONS OF THE CLEVELAND ELECTRIC ILLUMINATING COMPANY, CLEVELAND, OHIO

Watterson & Schneider, Architects, Cleveland, Ohio.

TABLE III

Two Wires in One Conduit

Size Wire, B. & S. G.	Loricated Conduit, Unlined; D B Wire
No. 14	½ inch.
" 12	½ inch or ¾ "
" 10	¾ "
" 8	1 "
" 6	1 "
" 5	1 " or 1¼ "
" 4	1¼ "
" 3	1¼ "
" 2	1¼ " or 1½ "
" 1	1½ "
" 0	1½ "
" 00	1½ " or 2 "
" 000	2 "
" 0000	2 "
250,000 C. M.	2 " or 2½ "
300,000 C. M.	2½ "
350,000 C. M.	2½ "
400,000 C. M.	2½ " or 3 "
450,000 C. M.	3 "
500,000 C. M.	3 "
600,000 C. M.	3 "
700,000 C. M.	3 "

TABLE IV

Three Wires in One Conduit

Size Wire, B. & S. G.		Loricated Tube, Unlined; D. B. Wire
Outside	Center	
No. 14	No. 12	¾ inch
" 12	" 10	¾ "
" 10	" 8	1 "
" 8	" 6	1 "
" 6	" 4	1¼ "
" 5	" 2	1¼ "
" 4	" 1	1¼ inch or 1½ "
" 3	" 0	1½ "
" 2	" 2/0	1½ " or 2 "
" 1	" 3/0	2 "
" 0	" 4/0	2 "
" 2/0	250 M.	2 " or 2½ "
" 3/0	300 M.	2½ "
" 4/0	400 M.	2½ "
250 M.	450 M.	2½ " or 3 "
250 M.	500 M.	3 "
300 M.	600 M.	3 "
350 M.	700 M.	3 "
400 M.	800 M.	3 "
450 M.	900 M.	3 "

using these tables, for the reason that the sizes of conductors which may be safely installed in any run of conduit depend, of course, upon the length of and the number of bends in the run. The tables are based on average conditions where the run does not exceed 90 to 100 feet, without more than three or four bends, in the case of the smaller sizes of wires for a given size of conduit; and where the run does not exceed 40 to 50 feet, with not more than one or two bends, in the case of the larger sizes of wires, for the same sizes of conduit.

Unlined conduit can be bent without injury to the conduit, if the conduit is properly made and if proper means are used in making the bends. Care should be exercised to avoid flattening the tube as a result of making the bend over a sharp curve or angle.

In installing iron conduits, the conduits should cross sleepers or beams at right angles, so as to reduce the amount of cutting of the beams or sleepers to a minimum.

Where a number of conduits originate at a center of distribution, they should be run at right angles for a distance of two or three feet from the cut-out box, in order to obtain a symmetrical and workmanlike arrangement of the conduits, and so as to have them enter the cabinet in a neat manner. While it is usual to use red or white lead at the joints of conduits in order to make them water-tight, this is frequently unnecessary in the case of enameled conduit, as there is often sufficient enamel on the thread to make a water-tight joint.

When iron conduits are installed in ash concrete, in Keene cement, or, in general, where they are subject in any way to corrosive action, they should be coated with asphaltum or other similar protective paint to prevent such action.

While the cost of circuit work run in iron conduits is usually greater than any other method of wiring, it is the most permanent and durable, and is strongly recommended where the first cost is not the sole consideration. This method of wiring should always be used in fireproof buildings, and also in the better class of frame buildings. It is also to be recommended for exposed work where the work is liable to disturbance or mechanical damage.

Wires Run in Flexible Metal Conduit. This form of conduit, shown in Fig. 2, is described by the manufacturers as a conduit composed of "concave and convex metal strips wound spirally upon each other in such a manner as to interlock several concave surfaces and present their convex surfaces, both exterior and interior, thereby securing a smooth and comparatively frictionless surface inside and out."

The field for the use of this form of conduit is rapidly increasing. Owing to its flexibility, conduit of this type can be used in numerous cases where the rigid conduit could not possibly be employed. Its use is to be recommended above all the other forms of wiring, except that installed in rigid conduits. For new fireproof buildings, it is not so durable as the rigid conduit, because not so water-tight; and it is very difficult, if not impossible, to obtain as workmanlike a conduit system with the flexible as with the rigid type of conduit. For completed or old frame buildings, however, the use of the flexible conduit is superior to all other forms of wiring.

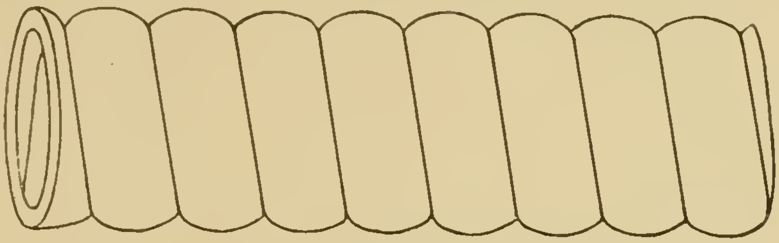


Fig. 2. Flexible Steel Conduit.
Courtesy of Sterling Electric Co., Troy, N. Y.

Table V gives the inside diameter of various sizes of flexible conduit, and the lengths of standard coils. The inside diameter of this conduit is the same as that of the rigid conduit; and the table given for the maximum sizes of conductors which may be installed in the various sizes of conduits, may be used also for flexible steel conduits, except that a little more margin should be allowed for flexible steel conduits than for the rigid conduits, as the stiffness of the latter makes it possible to pull in slightly larger sized conductors.

TABLE V

Greenfield Flexible Steel Conduit

Inside Diameter	Approximate Feet in Coil
$\frac{5}{16}$ inch	200
$\frac{3}{8}$ "	200
$\frac{1}{2}$ "	100
$\frac{3}{4}$ "	50
1 "	50
$1\frac{1}{4}$ inches	50
$1\frac{1}{2}$ "	50
2 "	Random Lengths
$2\frac{1}{2}$ "	" "
3 "	" "

This conduit should, of course, be first installed without the conductors, in the same manner as the rigid conduit. Owing to the flexibility of this conduit, however, it is absolutely essential to fasten it securely at all elbows, bends, or offsets; for, if this is not done, considerable difficulty will be experienced in drawing the conductors in the conduit.

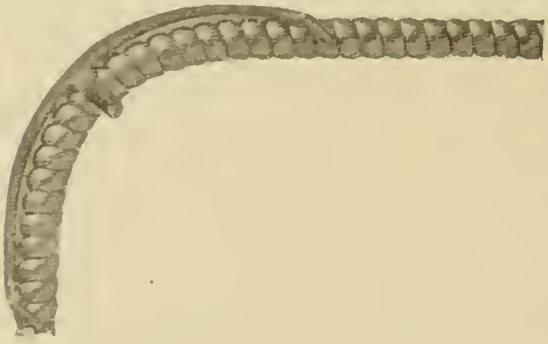


Fig. 3. Use of Elbow Clamp for Fastening Flexible Conduit in Place.

The rules governing the installation of this conduit are the same as those covering rigid conduits. Double-braided conductors are required, and the conduit should be grounded as required by the *Code Rules*. As already stated, the conduit should be securely fastened (in not less than three places) at all elbows; or else the special elbow clamp made for this purpose, shown in Fig. 3, should be used.

In order to cut flexible steel conduit properly, a fine hack saw should be employed. Outlet-boxes are required at all outlets, as well as bushing and wires to rigid conduit. Fig. 4 shows a coil of flexible steel conduit. Figs. 5, 6, and 7 show, respectively, an outlet box and cover, outlet plate, and bushing used for this conduit.

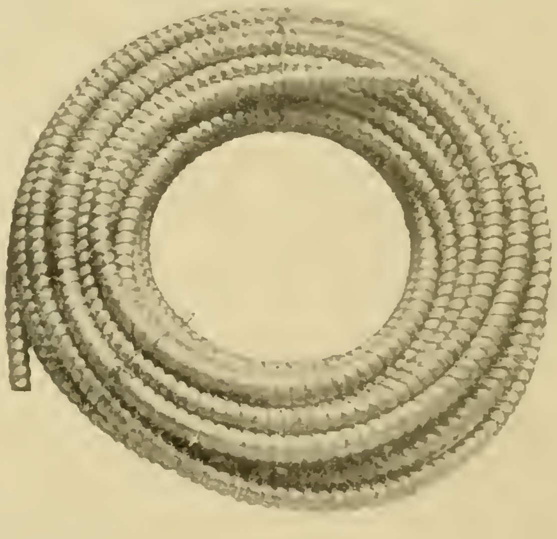


Fig. 4. A 100-Foot Coil of Flexible Steel Conduit.
Courtesy of Sprague Electric Co., New York, N. Y.

Armored Cable. There are many cases where it is impossible to install a conduit system. In such cases, probably the next best results may be obtained by the use of *steel armored cable.* The rules governing the installation of armored cable are given in the *National Electric Code,* under Section 24-A, and Section 48; also in 24-S. This cable is shown in Fig. 8.

Steel armored cable is made by winding formed steel strips over the insulated conductors. The steel strips are similar to those used for the steel conduit. Care is taken in forming the cable, to avoid crushing or abraiding the insulation on the conductors as the steel strips are fed and formed over the same. In the process of manufacture, the spools of steel ribbon are of irregular length, and when a spool is empty, the machine is stopped, and the ribbon is started on the next spool, the process being continued. There is no reason why the conduit cables could not be made of any length; but their actual lengths as made are determined by convenience in handling. Armored

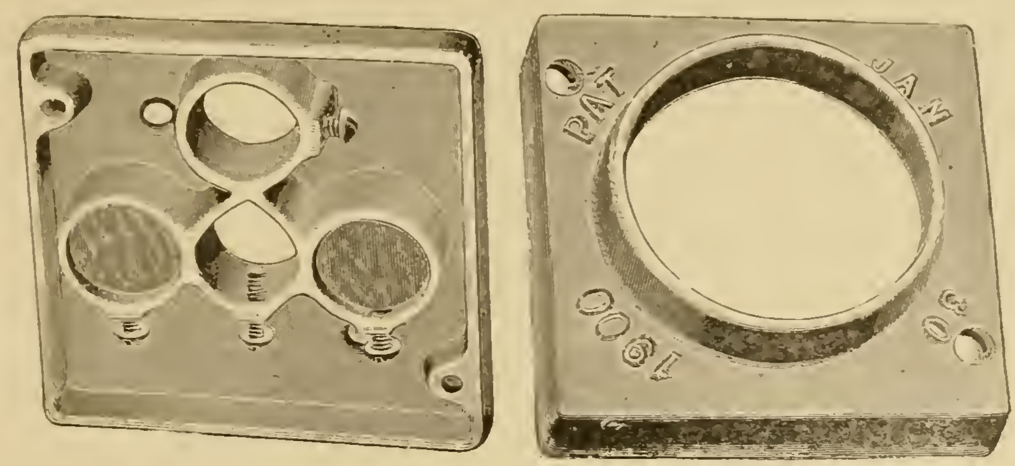


Fig. 5. Outlet Box for Flexible Steel Conduit.

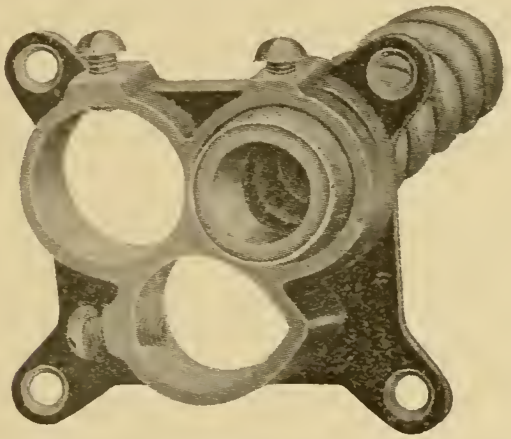


Fig. 6. Outlet Plate for Flexible Steel Conduit.

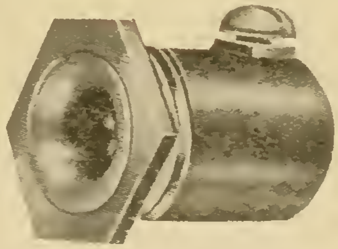


Fig. 7. Outlet Bushing.
Courtesy of Sprague Electric Co., New York, N. Y.

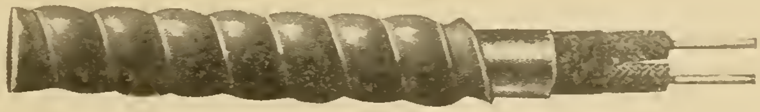


Fig. 8. Flexible Armored Cable. Twin Conductors.
Courtesy of Sprague Electric Co., New York, N. Y.

cable is made in *single conductors* from No. 1 to No. 10 B. & S. G.; in *twin conductors,* from No. 6 to No. 14 B. & S. G.; and *three-conductor* cable, from No. 10 to No. 14 B. & S. G. Table VI gives various data relating to armored conductors:

TABLE VI

Armored Conductors—Types, Dimensions, Etc.

Size B. & S. Gauge	Type and Number of Conductors	Outside Diameter (Inches)
No. 14	BX twin conductor	.63
“ 12	“ “ “	.685
“ 10	“ “ “	.725
“ 8	“ “ “	.875
“ 6	“ “ “	1.3125
“ 14	BM twin conductor (for marine work—ship wiring)	.725
“ 12	“ “ “	.725
“ 10	“ “ “	.73
“ 14	BX3 three conductor	.71
“ 12	“ “ “	.725
“ 10	“ “ “	.73
“ 14	BXL twin conductor, leaded	725
“ 12	“ “ “ “	.725
“ 10	“ “ “ “	.87
“ 14	BXL3 three conductor, leaded	.90
“ 12	“ “ “ “	.90
“ 10	“ “ “ “	.94
“ 10	Type D single conductor, stranded	.550
“ 8	“ “ “ “ “	.550
“ 6	“ “ “ “ “	.575
“ 4	“ “ “ “ “	.700
“ 2	“ “ “ “ “	.900
“ 1	“ “ “ “ “	.965
“ 10	Type DL single conductor, stranded, leaded	.625
“ 8	“ “ “ “ “ “	.710
“ 6	“ “ “ “ “ “	.700
“ 4	“ “ “ “ “ “	.760
“ 2	“ “ “ “ “ “	.920
“ 1	“ “ “ “ “ “	.910
	Steel Armored Flexible Cord	
“ 18	Type E twin conductor	.40
“ 16	“ “ “ “	.40
“ 14	“ “ “ “	.47
“ 18	Type EM twin conductor, re-inforced	.575
“ 16	“ “ “ “ “	.585
“ 14	“ “ “ “ “	.595

In Table VI, Types D (single), BX (twin), and BX3 (3 conductors) are armored cable adapted for ordinary indoor work. Type BM (twin conductors) is adapted for marine wiring. Types DL (single), BXL (twin), and BXL 3 (3 conductors) have the conductors lead-encased, with the steel armor outside, and are especially adapted for damp places, such as breweries, stables, and similar places.

Type E is used for flexible-cord pendants, and is suitable for factories, mills, show windows, and other similar places. Type EM is the same as Type E; but the flexible cord is reinforced, and is suitable for marine work, for use in damp places, and in all cases where it will be subject to very rough handling.

While this form of wiring has not the advantage of the conduit system—namely, that the wires can be withdrawn and new wires inserted without disturbing the building in any way whatever—yet it has many of the advantages of the flexible steel conduit, and it has some additional advantages of its own. For example, in a building already erected, this cable can be fished between the floors and in the partition walls, where it would be impossible to install either rigid conduit or flexible steel conduit without disturbing the floors or walls to an extent that would be objectionable.

Armored conductors should be continuous from outlet to outlet, without being spliced and installed on the loop system. Outlet boxes should be installed at all outlets, although, where this is impossible, outlet plates may be used under certain conditions. Clamps should be provided at all outlets, switch-boxes, junction-boxes, etc., to hold the cable in place, and also to serve as a means of grounding the steel sheathing.

Armored cable is less expensive than the rigid conduit or the flexible steel conduit, but more expensive than cleat wiring or knob and tube wiring, and is strongly recommended in preference to the latter.

WIRES RUN IN MOULDING

Moulding is very extensively used for electric circuit work, in extending circuits in buildings which have already been wired, and also in wiring buildings which were not provided with electric circuit work at the time of their erection. The reason for the popularity of moulding is that it furnishes a convenient and fairly good-looking runway for the wires, and protects them from mechanical injury.

It seems almost unwise to place conductors carrying electric current, in wood casing; but this method is still permitted by the *National Electric Code*, although it is not allowed in damp places or in places where there is liability to dampness, such as on brick walls, in cellars, etc.

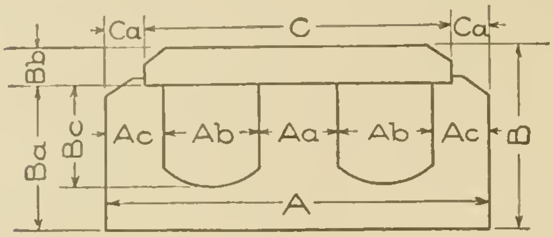


Fig. 9. Two-Wire Wood Moulding.

The dangers from the use of moulding are that if the wood becomes soaked with water, there will be a liability to leakage of current between the conductors run in the grooves of the moulding, and to fire being thereby started, which may not be immediately discovered. Furthermore, if the conductors are overloaded, and consequently overheated, the wood is likely to become charred and finally ignited. Moreover, the moulding itself is always a temptation as affording a good "round strip" in which to drive nails, hooks, etc. However, the convenience and popularity of moulding cannot be denied; and until some better substitute is found, or until its use is forbidden by the *Rules*, it will continue to be used to a very great extent for running circuits outside of the walls and on the ceilings of existing buildings. Figs. 9, 10, 11, and 12 show two- and three-wire moulding respectively; and Table VII gives complete data as to sizes of the moulding required for various sizes of conductors.

While the *Rules* recommend the use of hardwood moulding, as a matter of fact probably 90 per cent of the moulding used is of whitewood or other similar cheap, soft wood. Georgia pine or oak ordinarily

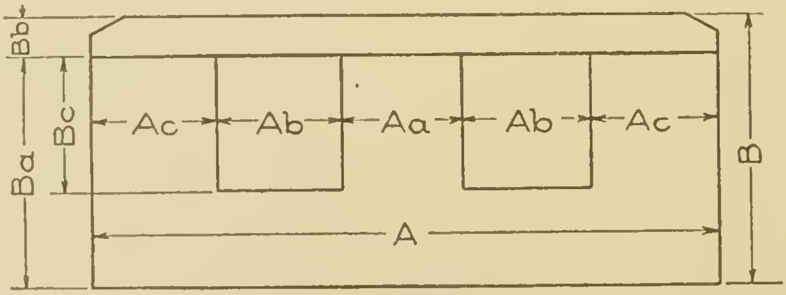


Fig. 10. Two-Wire Wood Moulding.

costs about twice as much as the soft wood. In designing moulding work, if appearance is of importance, the moulding circuits should be laid out so as to afford a symmetrical and complete design. For example, if an outlet is to be located in the center of the ceiling, the moulding should be continued from wall to wall, the portion beyond the outlet, of course, having no conductors inside of the moulding. If four outlets are to be placed on the ceiling, the rectangle of moulding should be completed on the fourth side, although, of course, no conductors need be placed in this portion of the moulding. Doing this increases the cost but little and adds greatly to the appearance.

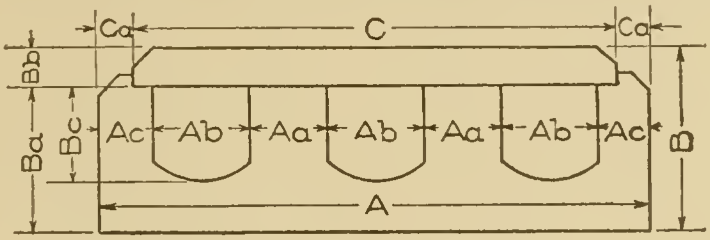


Fig. 11. Three-Wire Wood Moulding.

Moulding is frequently used in combination with other methods of wiring, including armored cable, flexible steel tubing, and fibrous tubing. In many instances, it is possible to fish tubing between beams or studs running in a certain direction; but when the conductors are to run in another direction or at right angles to the beams or studs, exposed work is necessary. In such cases, a junction-box or outlet-box must be placed at the point of connection between the moulding and the armored cable or steel tubing.

Where circuits are run in moulding, and pass through the floor, additional protection must be provided, as required by the *Code Rules*, to protect the moulding. As a rule, it is better to use conduit for all portions of moulding within six feet of the floor, so as to avoid the possibility of injury to the circuits. Where a combination of iron conduit or flexible steel tubing is used with moulding, it is well to use double-braided conductors throughout, because, although only single-

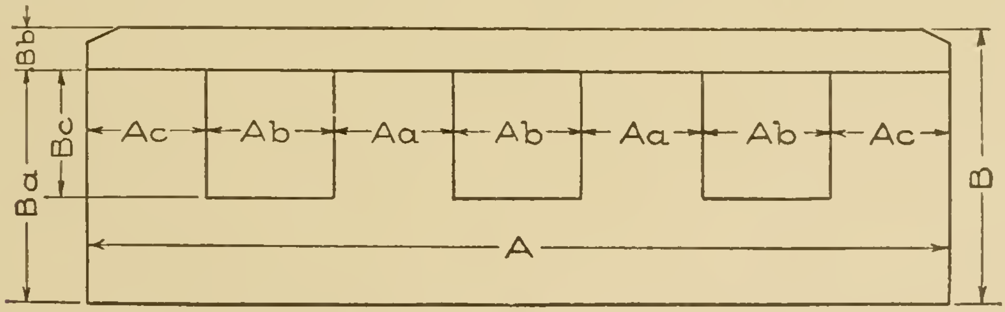


Fig. 12. Three-Wire Wood Moulding.

TABLE VII

Sizes of Mouldings Required for Various Sizes of Conductors

FIG. No.	TYPE OF MOULDING	NUMBER OF WIRES	MAXIMUM SIZE OF WIRE B AND S. GAUGE		DIMENSIONS IN INCHES									
			SOLID	STRANDED	A	Aa	Ab	Ac	B	Ba	Bb	Bc	C	Ca
9	A-2	2	12	14	1 1/2	1/2	1/4	1/4	27/32	5/8	7/32	1/4	1 1/8	3/16
9	A-4	2	8	10	1 11/16	1/2	5/16	9/32	29/32	11/16	7/32	5/16	1 5/16	3/16
9	A-6	2	4	5	2	1/2	7/16	5/16	1 1/16	13/16	1/4	7/16	1 9/16	7/32
9	A-8	2	1	2	2 3/8	1/2	9/16	3/8	1 3/16	15/16	1/4	9/16	1 13/16	9/32
9	A-9	2	–	3/0	3	5/8	3/4	7/16	1 13/32	1 1/8	9/32	3/4	2 7/16	9/32
10	A-10	2	–	250,000 C.M.	3 15/16	11/16	7/8	3/4	1 11/16	1 3/8	5/16	7/8	—	—
10	A-11	2	–	400,000 C.M.	4 7/8	15/16	1	31/32	2 3/16	1 7/8	5/16	1	—	—
11	B-2	3	12	14	2 3/16	7/16	1/4	9/32	27/32	5/8	7/32	1/4	1 13/16	3/16
11	B-4	3	8	10	2 1/2	15/32	5/16	5/16	29/32	11/16	7/32	5/16	2 1/8	3/16
11	B-6	3	4	5	2 7/8	13/32	7/16	3/8	1 1/16	13/16	1/4	7/16	2 3/8	1/4
11	B-8	3	1	2	3 5/8	19/32	9/16	3/8	1 3/16	15/16	1/4	9/16	3 1/16	9/32
11	B-9	3	–	3/0	4 5/16	9/16	3/4	15/32	1 13/32	1 1/8	9/32	3/4	3 3/4	9/32
12	B-10	3	–	250,000 C.M.	5 1/2	23/32	7/8	23/32	1 11/16	1 3/8	5/16	7/8	—	—
12	B-11	3	–	400,000 C.M.	6 3/4	15/16	1	15/16	2 3/16	1 7/8	5/16	1	—	—

braided conductors are required with moulding, double-braided conductors are required with unlined conduit, and if double-braided conductors were not used throughout, it would be necessary to make a joint at the outlet-box where the moulding stopped and the conduit work commenced. Where the conductors pass through floors, in moulding work, and where iron conduit is used, the inspection authorities, in order to protect the wire, usually require that a fibrous tubing be used as additional protection for the conductors inside of the iron pipe, although, if double-braided wire is used, this will not usually be required. Fig. 13 shows a fuseless cord rosette for use with moulding work. Fig. 14 shows a device for making a *tap* in moulding wiring.

Moulding work, under ordinary conditions, costs about one-half as much as circuit run in rigid conduit, and about 75 per cent, under ordinary conditions, of the cost of armored cable. Where the latter method of wiring or the conduit system can be employed, one or the other of these two methods should be used in preference to moulding, as the work is not only more substantial, but also safer. Various forms of metal moulding have been introduced, but up to the present time have not met with the success which they deserve.

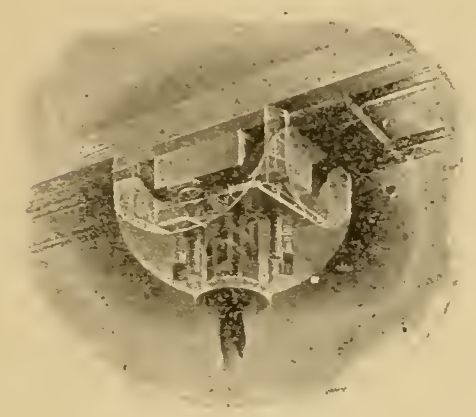


Fig. 13 Fuseless Cord Rosette.
Courtesy of Crouse-Hinds Co., Syracuse, N. Y.

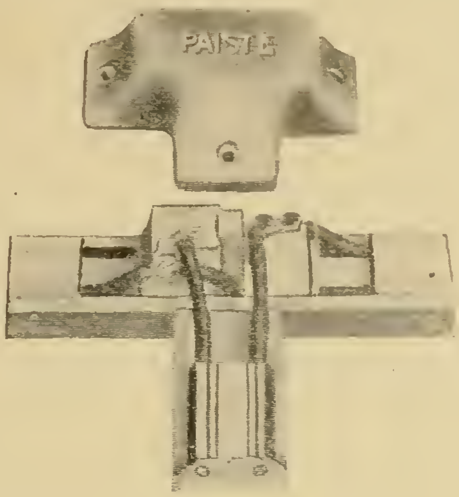


Fig. 14. Device for Making "Tap" in Moulding.
Courtesy of H. T. Paiste Co., Philadelphia, Pa.

CONCEALED KNOB AND TUBE WIRING

This method of wiring is still allowed by the *National Electric Code,* although many vigorous attempts have been made to have it abolished. Each of these attempts has met with the strongest opposition from contractors and central stations, particularly in small towns and villages, the argument for this method being, that it is the cheapest method of wiring, and that if it were forbidden, many places which are wired according to this method would not be wired at all, and the use of electricity would therefore be much restricted, if not entirely done away with, in such communities. This argument, however, is only a temporary makeshift obstruction in the way of inevitable progress, and in a few years, undoubtedly, the concealed knob and tube method will be forbidden by the *National Electric Code.*

The cost of wiring according to this method is about one-third of the cost of circuits run in rigid conduit, and about one-half of the cost of circuits run in armored cable. The latter method of wiring is rapidly replacing knob and tube wiring, and justly so, wherever the additional price for the latter method of wiring can be obtained. As the name indicates, this method of wiring employs *porcelain knobs and tubes*, the circuit work being run *concealed* between the floor beams and studs of a frame building. The knobs are used when the circuits run parallel to the floor beams; and the porcelain tubes are used when the circuits are run at right angles to the floor beams.

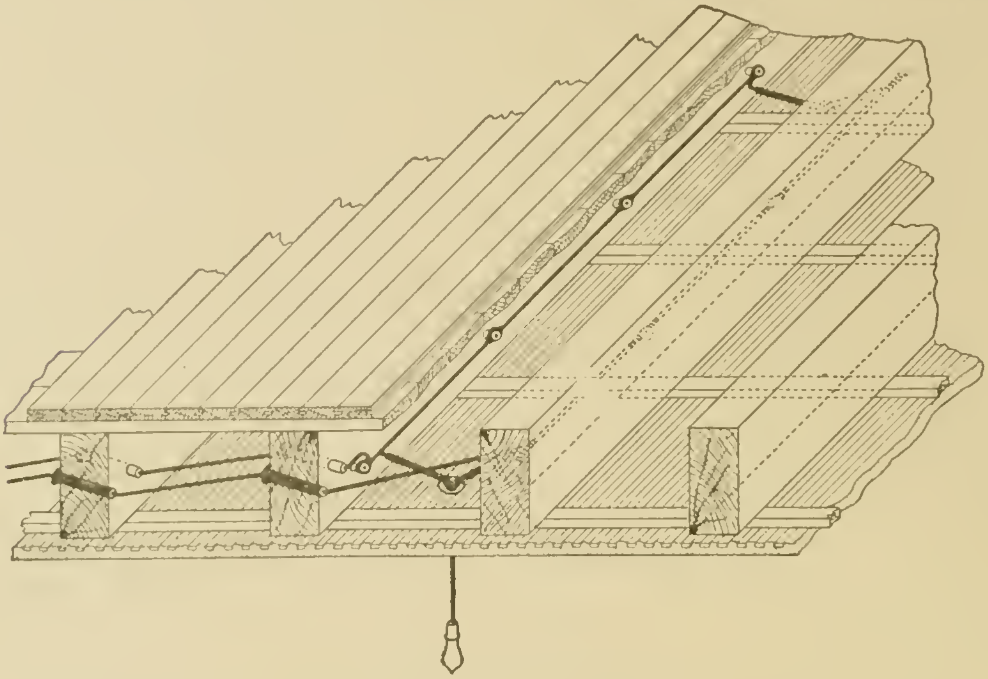


Fig. 15. Knob and Tube Wiring.

Fig. 15 shows an example of knob and tube wiring. In concealed knob and tube wiring, the wires must be separated at least ten inches from one another, and at least one inch from the surface wired over, that is, from the beams, flooring, etc., to which the insulator is fastened. Fig. 16 shows a good type of porcelain knob for this class of wiring. For knob and tube wiring, it will be noted that, owing to the fact that the wiring is concealed, the conductors must be kept further apart than in the case of exposed or open wiring on insulators, where, except in damp places, the wires may be run on cleats or on insulators only one-half inch from the surface wired over.

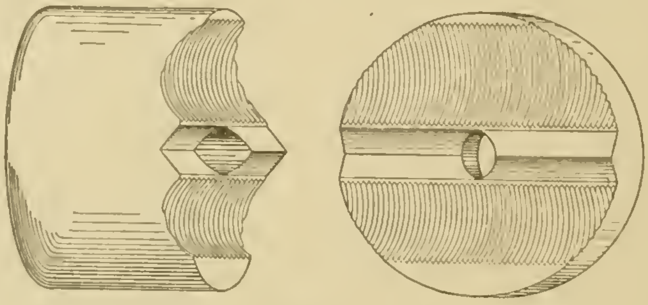


Fig. 16. Porcelain Knob.

Fibrous Tubing. Fibrous tubing is frequently used with knob and tube wiring, and the regulations governing its use are given in Rule 24, Section S, of the *National Electric Code.* This tubing, as stated in this *Rule,* may be used where it is impossible and impracticable to employ knobs and tubes, provided the difference in potential between the wires is not over 300 volts, and if the wires are not subject to moisture. The cost of wiring in flexible fibrous tubing is approximately about the same as the cost of knob and tube wiring. Duplex conductors, or two wires together are not allowed in fibrous tubing.

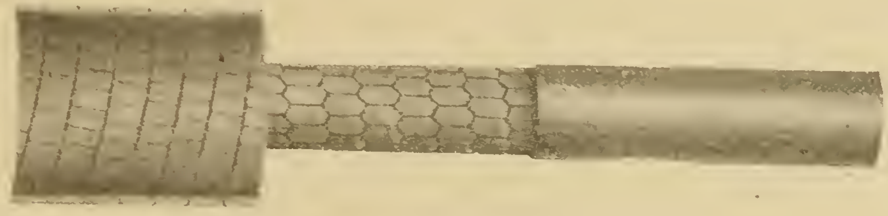


Fig. 17. Flexible Tubing, "Flexduct" Type.
Courtesy of National Metal Molding Co., Pittsburg, Pa.

Fibrous tubing is required at all outlets where conduit or armored cable is not used (as in knob and tube wiring); and, as required by the *Rules,* it must extend back from the last porcelain support to one inch beyond the outlet. Fig. 17 shows one make of fibrous tubing.

Table VIII gives the maximum sizes of conductors (double-braided) which may be installed in fibrous conduit.

TABLE VIII

Sizes of Conductors in Fibrous Conduit

OUTSIDE DIAMETER	INSIDE DIAMETER	ONE WIRE IN TUBE
$\frac{17}{32}$ inch	$\frac{1}{4}$ inch	No. 12
$\frac{21}{32}$ "	$\frac{3}{8}$ "	" 8
$\frac{25}{32}$ "	$\frac{1}{2}$ "	" 6
$\frac{15}{16}$ "	$\frac{5}{8}$ "	" 1
$1\frac{3}{32}$ "	$\frac{3}{4}$ "	" 2/0
$1\frac{5}{16}$ "	1 "	250,000 C. M.
$1\frac{9}{16}$ "	$1\frac{1}{4}$ "	400,000 C. M.
$1\frac{13}{16}$ "	$1\frac{1}{2}$ "	750,000 C. M.
$2\frac{1}{8}$ "	$1\frac{3}{4}$ "	1,000,000 C. M.
$2\frac{3}{8}$ "	2 "	1,500,000 C. M.
$2\frac{5}{8}$ "	$2\frac{1}{4}$ "	2,000,000 C. M.

WIRES RUN EXPOSED ON INSULATORS

This method of wiring has the advantages of cheapness, durability, and accessibility.

Cheapness. The relative cost of this method of wiring as compared with that of the concealed conduit system, is about fifty per cent of the latter if rubber-covered conductors are used, and about forty per cent of the latter if weatherproof slow-burning conductors are used. As the *Rules* of the Fire Underwriters allow the use of weatherproof slow-burning conductors in dry places, considerable saving may be effected by this method of wiring, provided there is no objection to it from the standpoint of appearance, and also provided that it is not liable to mechanical injury or disarrangement.

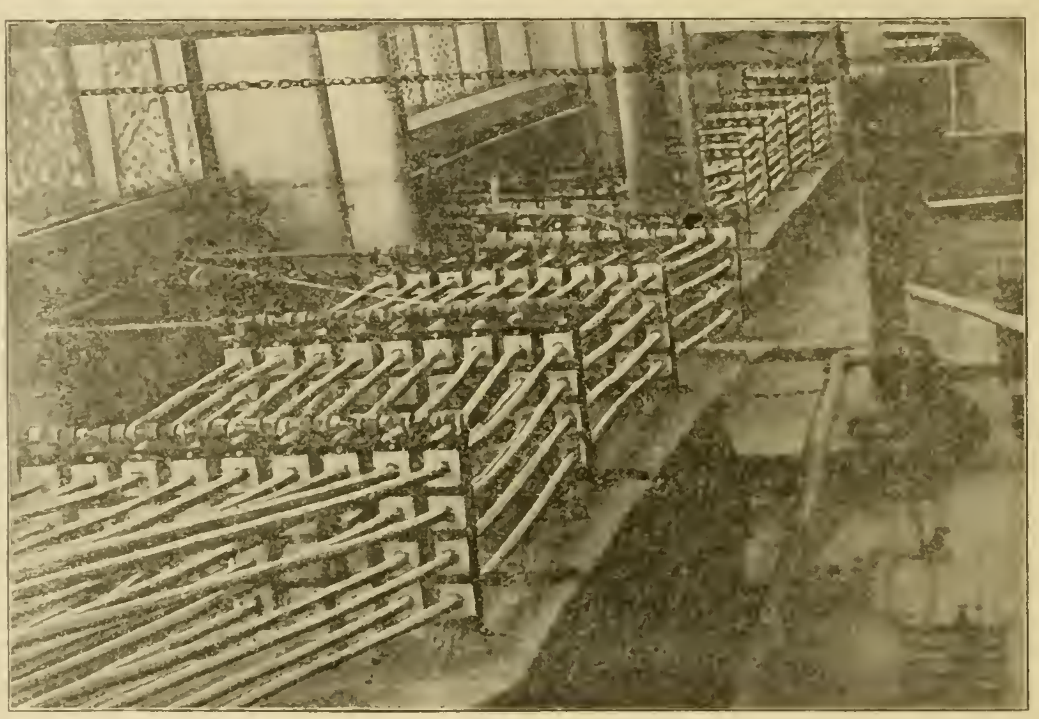


Fig. 18. Large Feeders Run Exposed on Insulators.

Durability. It is a well-known fact that rubber insulation has a relatively short life. Inasmuch as in this method of wiring, the insulation does not depend upon the insulation of the conductors, but on the insulators themselves, which are of glass or porcelain, this system is much more desirable than any of the other methods. Of course, if the conductors are mechanically injured, or the insulators broken, the insulation of the system is reduced; but there is no gradual deterioration as there is in the case of other methods of wiring, where rubber is depended upon for insulation. This is especially true in hot places, particularly where the temperature is 120° F. or above. For such cases, the weatherproof slow-burning conductors on porcelain or glass insulators are especially recommended.

Accessibility. The conductors being run exposed, they may be readily repaired or removed, or connections may be made to the same. This method of wiring is especially recommended for mills, factories, and for large or long feeder conductors. Fig. 18 shows examples of exposed large feeder conductors, installed in the New York Life Insurance Building, New York City. For small conductors, up to say No. 6 B. & S. Gauge each, porcelain cleats may be used to support one, two, or three conductors, provided the distance between the conductors is at least 2½ inches in a two-wire system, and 2½ inches between the two outside conductors in a three-wire system where the potential between the outside conductors is not over 300 volts. The cleat must hold the wire at least one-half inch from the surface to which the cleat is fastened; and in damp places the wire must be held at least one inch from the surface wired over. For larger conductors,

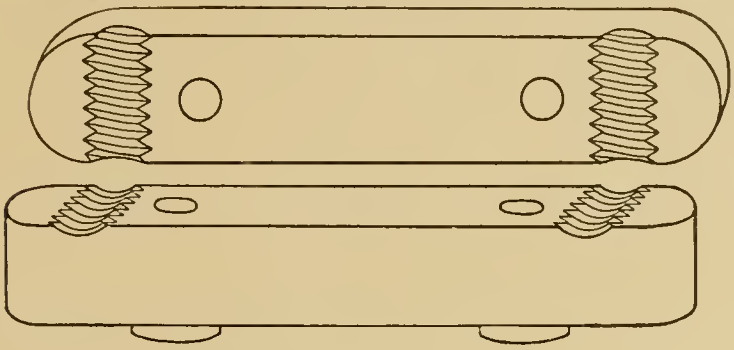


Fig. 19. Two-Wire Cleat.

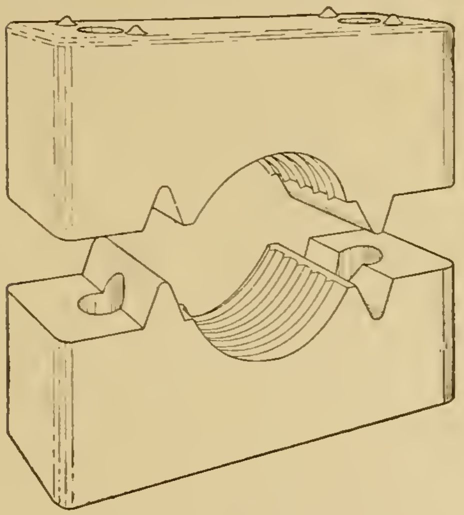


Fig. 20. One-Wire Cleat.

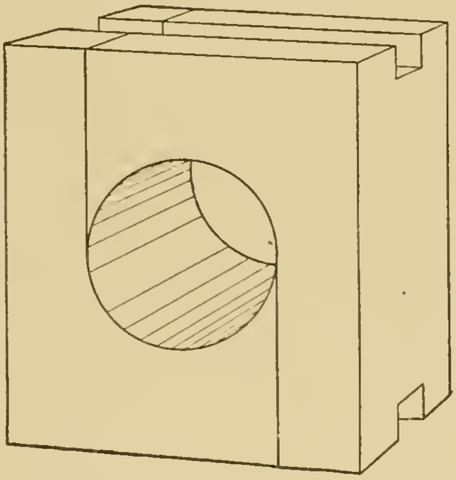


Fig. 21. Porcelain Insulator for Large Conductors.

from No. 6 to No. 4 / 0 B. & S. Gauge, it is usual to use single porcelain cleats or knobs. Figs. 19 and 20 show a good form of two-wire

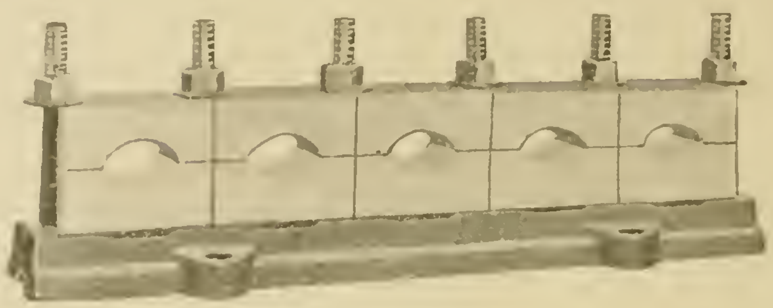


Fig. 22. Iron Rack and Insulators for Large Conductors.
Courtesy of General Electric Co., Schenectady, N. Y.

cleat and single-wire cleat, respectively.

For large feeder or main conductors from No. 4 / 0 B. & S. Gauge upward, a more substantial form of porcelain insulator should be used, such as shown in Fig. 21. These insulators are held in iron racks or angle-iron frames, of which two forms are shown in Figs. 22 and 23. The latter form of rack is particularly desirable for heavy conductors and where a number of conductors are run together. In this form of rack, any length of conductor can be removed without disturbing the other conductors.

As a rule, the porcelain insulators should be placed not more than $4\frac{1}{2}$ feet apart; and if the wires are liable to be disturbed, the distance between supports should be shortened, particularly for small conductors. If the beams are so far apart that supports cannot be obtained every $4\frac{1}{2}$ feet, it is necessary to provide a running board as shown in Fig. 24, to which the porcelain cleats and knobs can be fastened. Figs. 25 and 26 show two methods of supporting small conductors. For conductors of No. 8 B. & S.

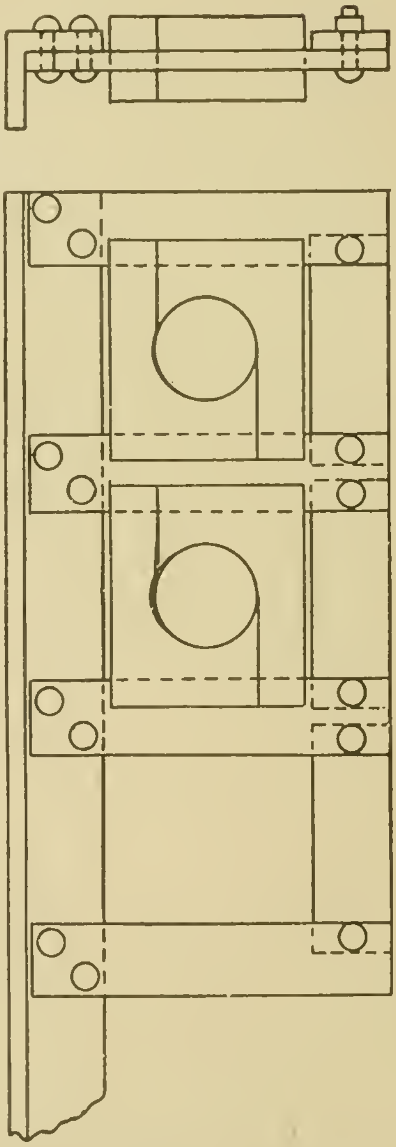
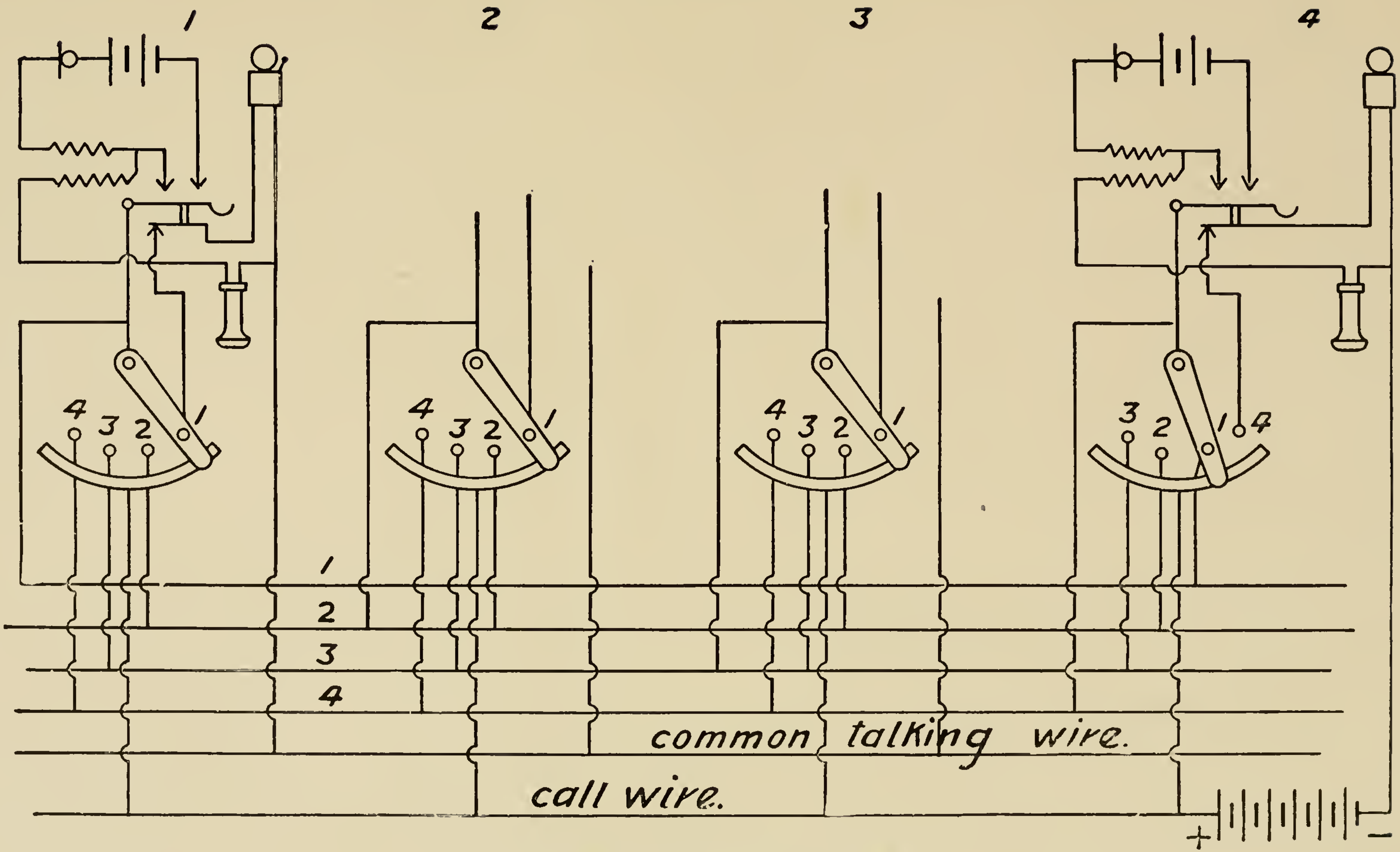


Fig. 23. Elevation and Plan of Insulators Held in Angle-Iron Frames.



INTERCOMMUNICATING HOUSE SYSTEM.

be protected by porcelain tubes, or, if the conductors be of rubber, by means of fibrous tubing placed inside of iron conduits.

All conductors on the walls for a height of not less than six feet from the ground, either should be boxed in, or, if they be rubber-covered, should (preferably) be run in iron conduits; and in conductors having single braid only, additional protection should be provided by means of flexible tubing placed inside of the iron conduit.

Where conductors cross each other, or where they cross iron pipes, they should be protected by means of porcelain tubes fastened with tape or in some other substantial manner that will prevent the tubes from slipping out of place.

TWO-WIRE AND THREE-WIRE SYSTEMS

As both the two-wire and the three-wire system are extensively used in electric wiring, it will be well to give some consideration to the advantages and disadvantages of each system, and to explain them somewhat in detail.

Relative Advantages. The choice of either a two-wire or a three-wire system depends largely upon the source of supply. If, for example, the source of supply will always probably be a 120-volt, two-wire system, there would be no object in installing a three-wire system for the wiring. If, on the other hand, the source of supply is a 120-240-volt system, the wiring should, of course, be made three-wire. Furthermore, if at the outset the supply were two-wire, but with a possibility of a three-wire system being provided later, it would be well to adapt the electric wiring for the three-wire system, making the neutral conductor twice as large as either of the outside conductors, and combining the two outside conductors to make a single conductor until such time as the three-wire service is installed. Of course, there would be no saving of copper in this last-mentioned three-wire system, and in fact it would be slightly more expensive than a two-wire system, as will be shortly explained.

The object of the three-wire system is to reduce the amount of copper—and consequently the cost of wiring—necessary to transmit a given amount of electric power. As a rule, the proposition is usually one of lighting and not of power, for the reason that by means of the three-wire system we are able to increase the potential at which the current is transmitted, and at the same time to take advantage of the greater efficiency of the lower voltage lamp. If current for power (motors, etc.) only were to be transmitted, it would be a simple matter to wind the motors, etc., for a higher voltage, and thereby reduce the weight of copper. If, however, we increase the voltage of lamps, we find that they are not so efficient, nor is their life so long. With the standard carbon lamp, it has been found that the 240-volt lamp, with the same life, requires about 10 to 12 per cent more current than the corresponding 120-volt lamp. Furthermore, in the case of the more efficient lamps recently introduced (such as the Tantalum lamp, Tungsten lamp, etc.), it has been found impracticable, if not impossible, to make them for pressures above 125 volts. For this reason the three-wire system is employed, for by this method we can use 240 volts across the outside conductors, and by the use of a neutral conductor obtain 120 volts between the neutral and the outside conductor, and thereby be enabled to use 120-volt lamps. Furthermore, if a 240-volt lamp should ever be placed on the market that was as economical as the lower voltage lamp, the result would be that the 240-480-volt system would be introduced, and 240-volt lamps used. As a matter of fact, this has been tried in several cities—and particularly in Providence, Rhode Island. As a rule, however, the 120-volt lamp has been found so much more satisfactory as regards life, efficiency, etc., that it is nearly always employed.

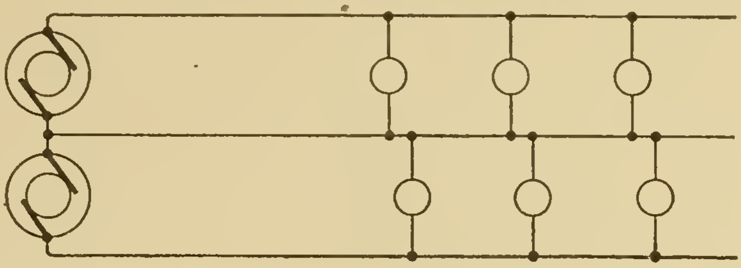


Fig. 29. Three-Wire System, with Neutral Conductor between the Two Outside Conductors.

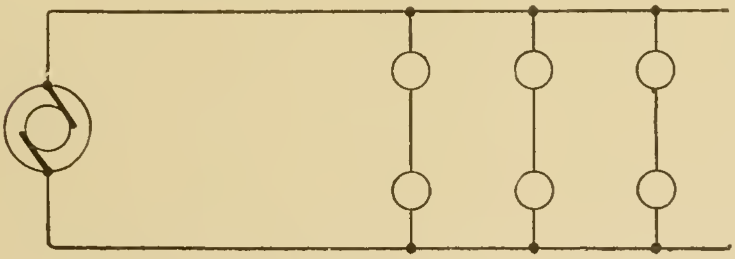


Fig. 30. Lamps Arranged in Pairs in Series, Dispensing with Necessity for Third or Neutral Conductor.

The two-wire system is so extremely simple that no explanation whatever is required concerning it.

The three-wire system, however, is somewhat confusing, and will now be considered.

Details of Three-Wire System. The three-wire system may be considered as a two-wire system with a third or neutral conductor placed between the two outside conductors, as shown in Fig. 29. This neutral conductor would not be required if we could always have the lamps arranged in pairs, as shown in Fig. 30. In this case, the two lamps would burn in series, and we could transmit the current at double the usual voltage, and thereby supply twice the number of lamps with one-quarter the weight of copper, allowing the same loss in pressure in the lamps. The reason for this is, that, having the lamps arranged in series of pairs, we reduce the current to one-half, and, as the pressure at which the current is transmitted is doubled, we can again reduce the copper one-half without increasing the loss in lamps. We therefore see that we have a double saving, as the current is reduced one-half, which reduces the weight of copper one-half, and we can again reduce the copper one-half by doubling the loss in volts without increasing the percentage loss. For example, if in one case we had a straight two-wire system transmitting current to 100 lamps at a potential of 100 volts, and this system were replaced by one in which the lamps were placed in series of pairs, as shown in Fig. 30, and the potential increased to 200 volts—100 lamps still being used—we should find, in the latter case, that we were carrying current really for only 50 lamps, as we would require only the same amount of current for two lamps now that we required for one lamp before. Furthermore, as the potential would now be 200 instead of 100 volts, we could allow twice as much loss as in the first case, because the loss would now be figured as a percentage of 200 volts instead of a percentage of 100 volts. From this, it will readily be seen that in the second case mentioned, we would require only one-quarter the weight of copper that would be required in the first case.

It will readily be seen, however, that a system such as that outlined in the second scheme having two lamps, would be impracticable for ordinary purposes, for the reason that it would always require the lamps to be burned in pairs. Now, it is for this very reason that the third or neutral conductor is required; and, if this conductor be added, it will no longer be necessary to burn the lamps in pairs. This, then, is the object of the three-wire system—to enable us to reduce the amount of copper required for transmitting current, without increasing the electric pressure employed for the lamps.

With regard to the size of the neutral conductor, one important point must be borne in mind; and that is, that the *Rules of the National Electric Code* require the neutral conductor in all interior wiring to be made at least as large as either of the two outside conductors. The reasons for this from a fire standpoint are obvious, because, if for any reason either of the outside conductors became disconnected, the neutral wire might be required to carry the same current as the outside conductors, and therefore it should be of the same capacity. Of course, the chances of such an event happening are slight; but, as the fire hazard is all-important, this rule must be complied with for interior wiring or in all cases where there would be a probability of fire. For outside or underground work, however, where the fire hazard would be relatively unimportant, the neutral conductor might be reduced in size; and, as a matter of fact, it is made smaller than the outside conductors.

The three-wire system is sometimes installed where it is desired to use the system as a two-wire, 125-volt system, or to have it arranged so that it may be used at any time also as a three-wire, 125-250-volt system. Of course, in order to do this, it is necessary to make the neutral conductor equal to the combined capacity of the outside conductors, the latter being then connected together to form one conductor, the neutral being the return conductor. This system is not recommended except in such instances, for example, as where an isolated plant of 125 volts is installed, and where there is a possibility of changing over at some future time to the three-wire, 125-250-volt system. In such a case as this, however, it would be better, where possible, to design the isolated plant for a three-wire, 125-250-volt system originally, and then to make the neutral conductor the same size as each of the two outside conductors.

The weight of copper required in a three-wire system where the neutral conductor is the same size as either of the two outside conductors, is $\frac{3}{8}$ of that required for a corresponding two-wire system using the same voltage of lamps.* It is obvious that this is true, because, as the discussion proved concerning the arrangement shown in Fig. 30, where the lamps were placed in series of pairs, we found that the weight of copper for the two conductors was one-quarter the weight of the regular two-wire system. It is then of course true, that, if we had another conductor of the same size as each of the outside conductors, we increase theweight of copper one-half, or one-quarter plus one-half of one-quarter—that is, three-eighths.

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*NOTE.—If, in the two-wire system, we represent the weight of each of the two conductors by $\frac{1}{2}$, the weight of each of the outside conductors in a three-wire system would be represented by $\frac{1}{8}$; and if we had three conductors of the same size, we would have $\frac{1}{8}+\frac{1}{8}+\frac{1}{8}=\frac{3}{8}$ of the weight of copper required in a three-wire system, which would be required in a corresponding two-wire system having the same percentage of loss and using the same voltage of lamps.

If the neutral conductor were made $\frac{1}{2}$ of the size of each of the outside conductors, as is sometimes done in underground work, the total weight of copper required would be $\frac{1}{8}+\frac{1}{8}+\frac{1}{16}=\frac{5}{16}$ of that required in the corresponding two-wire system.

In the three-wire system frequently used in isolated plants in which the two outside conductors are joined together and the neutral conductor made equal to their combined capacity, there is no saving of copper, for the reason that the same voltage of transmission is used, and, consequently, we have neither reduced the current nor increased the potential. Furthermore, though the weight of copper is the same, it is now divided into three conductors, instead of two, and naturally it costs relatively more to insulate and manufacture three conductors than to insulate and manufacture two conductors having the same total weight of copper. As a matter of fact, the three-wire system, having the neutral conductor equal to the combined capacity of the two outside ones, the latter being joined together, is about 8 to 10 per cent more expensive than the corresponding straight two-wire system.

In interior wiring, as a rule, where the three-wire system is used for the mains and feeders, the two-wire system is nearly always employed for the branch circuits. Of course, the two-wire branch circuits are then balanced on each side of the three-wire system, so as to obtain as far as possible at all times an equal balance on the two sides of the system. This is done so as to have the neutral conductor carry as little current as possible. From what has already been said, it is obvious that in case there is a perfect balance, the lamps are virtually in series of pairs, and the neutral conductor does not carry any current. Where there is an unbalanced condition, the neutral conductor carries the difference between the current on one side and the current on the other side of the system. For example, if we had five lamps on one side of the system and ten lamps on the other, the neutral conductor would carry the current corresponding to five lamps.

In calculating the three-wire system, the neutral conductor is disregarded, the outer wires being treated as a two-wire circuit, and the calculation is for one-half the total number of lamps, the percentage of loss being based on the potential across the two outside conductors.

The three-wire system is very generally employed in alternating-current secondary wiring, as nearly all transformers are built with three-wire connections.

While unbalancing will not affect the total loss in the outside conductors, yet it does affect the loss in the lamps, for the reason that the system is usually calculated on the basis of a perfect balance, and the loss is divided equally between the two lamps (the latter being considered in series of pairs). If, however, there is unbalancing to a great degree, the loss in lamps will be increased; and if the entire load is thrown over on one side, the loss in the lamps will be doubled on the remaining side, because the total loss in voltage will now occur in these lamps, whereas, in the case of perfect balance, it would be equally divided between the two groups of lamps.

CALCULATION OF SIZES OF CONDUCTORS

The formula for calculating the sizes of conductors for direct currents, where the length, load, and loss in volts are given, is as follows:

The size of conductor (in circular mils) is equal to the current *multiplied by* the distance (one way), *multiplied by* 21.6, *divided by* the loss in volts; or,

$$CM = \frac{C \times D \times 21.6}{V} \quad \dots\dots\dots\dots\dots (1)$$

in which C = Current, in amperes;
D = Distance or length of the circuit (one way, in feet);
V = Loss in volts between the beginning and end of the circuit.

The constant (21.6) of this formula is derived from the resistance of a mil foot of wire of 98 per cent conductivity at 25° Centigrade or 77° Fahrenheit. The resistance of a conductor of one mil diameter and one foot long, is 10.8 at the temperature and conductivity named. We multiply this figure (10.8) by 2, as the length of a circuit is usually given as the distance one way, and in order to obtain the resistance of both conductors in a two-wire circuit, we must multiply by 2. The formula as above given, therefore, is for a two-wire circuit; and in calculating the size of conductors in a three-wire system, the calculation should be made on a two-wire basis, as explained hereinafter.

Formula 1 can be transformed so as to obtain the loss in a given circuit, or the current which may be carried a given distance with a stated loss, or to obtain the distance when the other factors are given, in the following manner:

Formula for Calculating Loss in Circuit when Size, Current, and Distance are Given

$$V = \frac{C \times D \times 21.6}{CM} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Formula for Calculating Current which may be Carried by a Given Circuit of Specified Length, and with a Specified Loss

$$C = \frac{CM \times V}{D \times 21.6} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Formula for Calculating Length of Circuit when Size, Loss, and Current to be Carried are Given

$$D = \frac{CM \times V}{C \times 21.6} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Formulæ are frequently given for calculating sizes of conductors, etc., where the load, instead of being given in amperes, is stated in lamps or in horse-power. It is usually advisable, however, to reduce the load to amperes, as the efficiency of lamps and motors is a variable quantity, and the current varies correspondingly.

It is sometimes convenient, however, to make the calculation in terms of watts. It will readily be seen that we can obtain a formula expressed in watts from Formula 1. To do this, it is advisable to express the loss in volts in percentage, instead of actual volts lost. It must be remembered that, in the above formulæ, V represents the volts lost in the circuit, or, in other words, the difference in potential between the beginning and the end of the circuit, and is not the applied E. M. F. The loss in percentage, in any circuit, is equal to the actual loss expressed in volts, *divided by* the line voltage, *multiplied by* 100; or,

$$P = \frac{V}{E} \times 100.$$

From this equation, we have:

$$V = \frac{P\,E}{100}.$$

If, for example, the calculation is to be made on a loss of 5 per cent, with an applied voltage of 250, using this last equation, we would have:

$$V = \frac{5 \times 250}{100} = 12.5 \text{ volts.}$$

Substituting the equation $V = \frac{P\,E}{100}$ in Formula **1**, we have:

$$C\,M = \frac{C \times D \times 21.6}{\frac{P\,E}{100}}$$

$$= \frac{C \times D \times 21.6 \times 100}{P\,E}$$

$$= \frac{C \times D \times 2{,}160}{P\,E}.$$

This equation, it should be remembered, is expressed in terms of applied voltage. Now, since the power in watts is equal to the applied voltage *multiplied by* the current ($W = EC$), it follows that

$$C = \frac{W}{E}.$$

By substituting this value of C in the equation given above $\left(C\,M = \frac{C \times D \times 2{,}160}{P\,E}\right)$, the formula is expressed in terms of watts instead of current, thus:

$$CM = \frac{W \times D \times 2{,}160}{E\,P\,E}, \qquad \textbf{(5)}$$

in which W = Power in watts transmitted;
D = Length of the circuit (one way)—that is, the length of one conductor;
P = Figure representing the percentage loss;
E*= Applied voltage.

All the above formulæ are for calculations of two-wire circuits. In making calculations for three-wire circuits, it is usual to make the calculation on the basis of the two outside conductors; and in three wire calculations, the above formulæ can be used with a slight modification, as will be shown.

In a three-wire circuit, it is usually assumed in making the calculation, that the load is equally balanced on the two sides of the neutral conductor; and, as the potential across the outside conductors is double that of the corresponding potential across a two-wire circuit, it is evident that for the same size of conductor the total loss in volts could be doubled without increasing the percentage of loss in lamps. Furthermore, as the load on one side of the neutral conductor, when the system is balanced, is virtually in series with the load on the third side, the current in amperes is usually one-half the sum of the current required by all the lamps. If C be still taken as the total current in amperes (that is, the sum of the current required by all of the lamps) in Formula 1, we shall have to divide this current by 2, to use the formula for calculating the two outside conductors for a three-wire system. Furthermore, we shall have to multiply the voltage lost in the lamps by 2, to obtain the voltage lost in the two outside conductors, for the reason that the potential of the outside conductors is double the potential required by the lamps themselves. In other words, Formula 1 will become:

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*NOTE. Remember that V in Formulæ 1 to 4 represents the volts lost, but that E in Formula 5 represents the applied voltage.

$$CM = \frac{C \times D \times 21.6}{2 \times V \times 2}$$

$$= \frac{C \times D \times 21.6}{4V}, \qquad (6)$$

in which C = Sum of current required by all of the lamps on both sides of the neutral conductor;

D = Length of circuit—that is, of any one of the three conductors;

V = Loss allowed in the lamps, i. e., one-half the total loss in the two outside conductors.

In the same manner, all of the other formulæ may be adapted for making calculations for three-wire systems. Of course the calculation of a three-wire system could be made as if it were a two-wire system, by taking one-half the total number of lamps supplied, at one-half the voltage between the outside conductors.

It is understood, of course, that the size of the conductor in Formula 6 is the size of each of the two outside ones; but, inasmuch as the *Rules of the National Electric Code* require that for interior wiring the neutral conductor shall be at least equal in size to the outside conductors, it is not necessary to calculate the size of the neutral conductor. It must be remembered, however, that, in a three-wire system where the neutral conductor is made equal in capacity to the combined size of the two outside conductors, and where the two outside conductors are joined together, we have virtually a two-wire system arranged so that it can be converted into a three-wire system later. In this case the calculation is exactly the same as in the case of the two-wire circuits, except that one of the two conductors is split into two smaller wires of the same capacity. This is frequently done where isolated plants are installed, and where the generators are wound for 125 volts and it may be desired at times to take current from an outside three-wire 125-250-volt system.

METHOD OF PLANNING A WIRING INSTALLATION

The first step in planning a wiring installation, is to gather all the data which will affect either directly or indirectly the system of wiring and the manner in which the conductors are to be installed. These data will include: Kind of building; construction of building; space available for conductors; source and system of electric-current supply; and all details which will determine the method of wiring to be employed. These last items materially affect the cost of the work, and are usually determined by the character of the building and by commercial considerations.

Method of Wiring. In a modern fireproof building, the only system of wiring to be recommended is that in which the conductors are installed in rigid conduits; although, even in such cases, it may be desirable, and economy may be effected thereby, to install the larger feeder and main conductors exposed on insulators using weatherproof slow-burning wire. This latter method should be used, however, only where there is a convenient runway for the conductors, so that they will not be crowded and will not cross pipes, ducts, etc., and also will not have too many bends. Also, the local inspection authorities should be consulted before using this method.

For mills, factories, etc., wires exposed on cleats or insulators are usually to be recommended, although rigid conduit, flexible conduit, or armored cable may be desirable.

In finished buildings, and for extensions of existing outlets, where the wiring could not readily or conveniently be concealed, moulding is generally used, particularly where cleat wiring or other exposed methods of wiring would be objectionable. However, as has already been said, moulding should not be employed where there is any liability to dampness.

In finished buildings, particularly where they are of frame construction, flexible steel conduits or armored cable are to be recommended.

While in new buildings of frame construction, knob and tube wiring are frequently employed, this method should be used only where the question of first cost is of prime importance. While armored cable will cost approximately 50 to 100 per cent more than knob and tube wiring, the former method is so much more permanent and is so much safer that it is strongly recommended.

Systems of Wiring. The system of wiring—that is, whether the two-wire or the three-wire system shall be used—is usually determined by the source of supply. If the source of supply is an isolated plant, with simple two-wire generators, and with little possibility of current being taken from the outside at some future time, the wiring in the building should be laid out on the two-wire system. If, on the other hand, the isolated plant is three-wire (having three-wire generators, or two-wire generators with balancer sets), or if the current is taken from an outside source, the wiring in the building should be laid out on a three-wire system.

It very seldom happens that current supply from a central station is arranged with other than the three-wire system inside of buildings, because, if the outside supply is alternating current, the transformers are usually adapted for a three-wire system. For small buildings, on the other hand, where there are only a few lights and where there would be only one feeder, the two-wire system is used. As a rule, however, when the current is taken from an outside source, it is best to consult the engineer of the central station supplying the current, and to conform with his wishes. As a matter of fact, this should be done in any event, in order to ascertain the proper voltage for the lamps and for the motors, and also to ascertain whether the central station will supply transformers, meters, and lamps—for, if these are not thus supplied, they should be included in the contract for the wiring.

Location of Outlets. It is not within the scope of this treatise to discuss the matter of *illumination,* but it is desirable, at this point, to outline briefly the method of procedure.

A set of plans, including elevation and details, if any, and showing decorative treatment of the various rooms, should be obtained from the Architect. A careful study should then be made by the Architect, the Owner, and the Engineer, or some other person qualified to make recommendations as to illumination. The location of the outlets will depend: *First,* upon the decorative treatment of the room, which determines the æsthetic and architectural effects; *second,* upon the type and general form of fixtures to be used, which should be previously decided on; *third,* upon the tastes of the owners or occupants in regard to illumination in general, as it is found that tastes vary widely in regard to amount and kind of illumination.

The location of the outlets, and the number of lights required at each, having been determined, the outlets should be marked on the plans.

The Architect should then be consulted as to the location of the centers of distribution, the available points for the risers or feeders, and the available space for the branch circuit conductors.

In regard to the *rising points for the feeders and mains*, the following precautions should be used in selecting chases:

1. The space should be amply large to accommodate all the feeders and mains likely to rise at that given point. This seems trite and unnecessary, but it is the most usual trouble with chases for risers. Formerly architects and builders paid little attention to the requirements for chases for electrical work; but in these later days of 2-inch and 2½-inch conduit, they realize that these pipes are not so invisible and mysterious as the force they serve to distribute, particularly when twenty or more such conduits must be stowed away in a building where no special provision has been made for them.

2. If possible, the space should be devoted solely to electric wiring. Steam pipes are objectionable on account of their temperature; and these and all other pipes are objectionable in the same space occupied by the electrical conduits, for if the space proves too small, the electric conduits are the first to be crowded out.

The chase, if possible, should be continuous from the cellar to the roof, or as far as needed. This is necessary in order to avoid unnecessary bends or elbows, which are objectionable for many reasons.

In similar manner, the location of *cut-out cabinets or distributing centers* should fulfil the following requirements:

1. They should be accessible at all times.
2. They should be placed sufficiently close together to prevent the circuits from being too long.
3. Do not place them in too prominent a position, as that is objectionable from the Architect's point of view.
4. They should be placed as near as possible to the rising chases, in order to shorten the feeders and mains supplying them.

Having determined the system and method of wiring, the location of outlets and distributing centers, the next step is to lay out the *branch circuits* supplying the various outlets.

Before starting to lay out the branch circuits, a drawing showing the floor construction, and showing the space between the top of the beams and girders and the flooring, should be obtained from the Architect. In fireproof buildings of iron or steel construction, it is almost the invariable practice, where the work is to be concealed, to run the conduits over the beams, under the rough flooring, carrying them between the sleepers when running parallel to the sleepers, and notching the latter when the conduits run across them (see Fig. 31). In wooden frame buildings, the conduits run parallel to the beams and to the furring (see Fig. 32); they are also sometimes run below the beams. In the latter case the beams have to be notched, and this is allowable only in certain places, usually near the points where the beams are supported. The Architect's drawing is therefore necessary in order that the location and course of the conduits may be indicated on the plans.

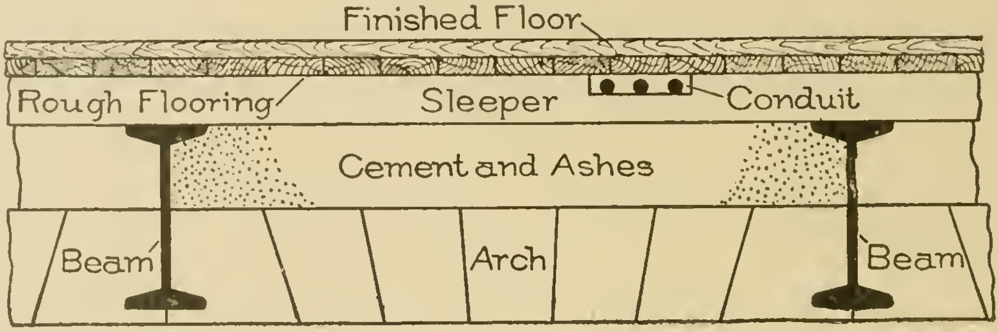


Fig. 31. Running Conductors Concealed under Floor in Fireproof Building.

The first consideration in laying out the branch circuit is the *number of outlets* and *number of lights* to be wired on any one branch circuit. The *Rules of the National Electric Code* (Rule 21-D) require that "no set of incandescent lamps requiring more than 660 watts, whether grouped on one fixture or on several fixtures or pendants, will be dependent on one cut-out." While it would be possible to have branch circuits supplying more than 660 watts, by placing various cut-outs at different points along the route of the branch circuit, so as to subdivide it into small sections to comply with the rule, this method is not recommended, except in certain cases, for exposed wiring in factories or mills. As a rule, the proper method is to have the cut-outs located at the center of distribution, and to limit each branch circuit to 660 watts, which corresponds to twelve or thirteen 50-watt lamps, twelve being the usual limit. Attention is called to the fact that the inspectors usually allow 50 watts for each socket connected to a branch circuit; and although 8-candle-power lamps may be placed at some of the outlets, the inspectors hold that the standard lamp is approximately 50 watts, and for that reason there is always the likelihood of a lamp of that capacity being used, and their inspection is based on that assumption. Therefore, to comply with the requirements, an allowance of not more than twelve lamps per branch circuit should be made.

In ordinary practice, however, it is best to reduce this number still further, so as to make allowance for future extensions or to increase the number of lamps that may be placed at any outlet. For this reason, it is wise to keep the number of the outlets on a circuit at the lowest point consistent with economical wiring. It has been proven by actual practice, that the best results are obtained by limiting the number to five or six outlets on a branch circuit. Of course, where all the outlets have a single light each, it is frequently necessary, for reasons of economy, to increase this number to eight, ten, and, in some cases, twelve outlets.

We have already referred to the location of the wires or conduits. This question is generally settled by the peculiarities of the construction of the building. It is necessary to know this, however, before laying out the circuit work, as it frequently determines the course of a circuit.

Now, as to the course of the circuit work, little need be said, as it is largely influenced by the relative position of the outlets, cut-outs, switches, etc. Between the cut-out box and the first outlet, and between the outlets, it will have to be decided, however, whether the circuits shall run at right angles to the walls of the building or room, or whether they shall run direct from one point to another, irrespective of the angle they make to the sleepers or beams. Of course, in the former case, the advantages are that the cost is somewhat less and the number of elbows and bends is reduced. If the

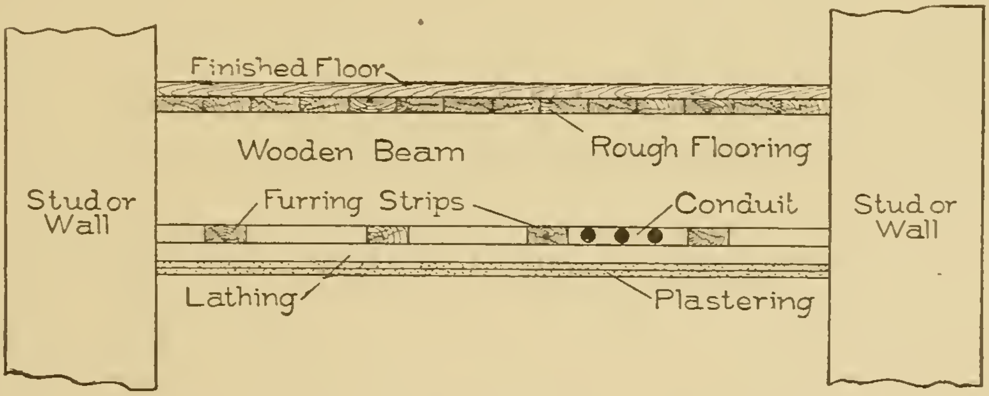


Fig. 32. Running Conductors Concealed under Floor in Wooden Frame Building.

tubes are bent, however, instead of using elbows, the difference in cost is usually very slight, and probably does not compensate for the disadvantages that would result from running the tubes diagonally. As to the number of bends, if branch circuit work is properly laid out and installed, and a proper size of tube used, it rarely happens that there is any difference in "pulling" the branch circuit wires. It may happen, in the event of a very long run or one having a large number of bends, that it might be advisable to adopt a short and most direct route.

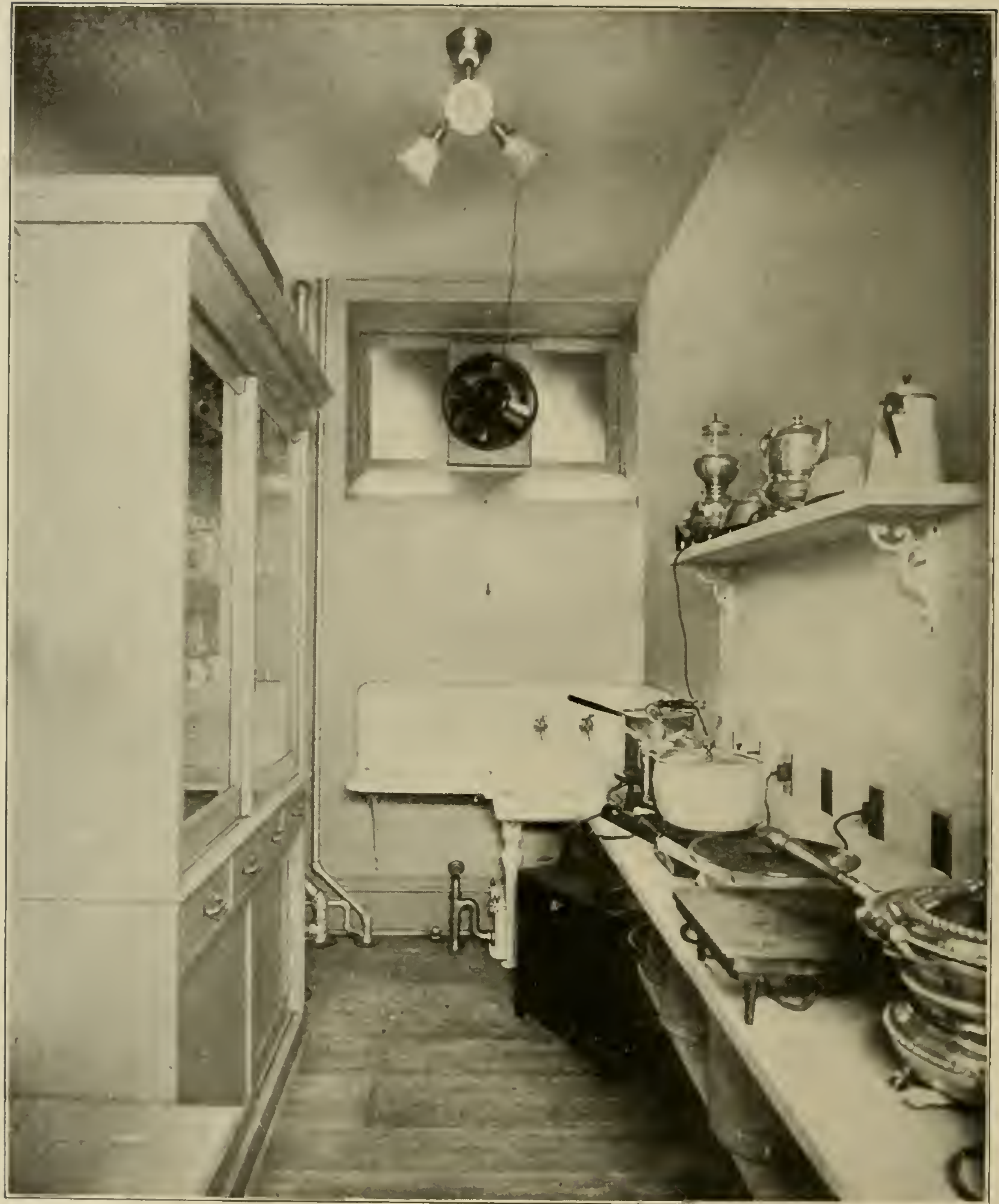
Up to this time, the location of the distribution centers has been made solely with reference to architectural considerations; but they must now be considered in conjunction with the branch circuit work.

It frequently happens that, after running the branch circuits on the plans, we find, in certain cases, that the position of centers of distribution may be changed to advantage, or sometimes certain groups may be dispensed with entirely and the circuits run to other points. We now see the wisdom of ascertaining from the Architect where cut-out groups may be located, rather than selecting particular points for their location.

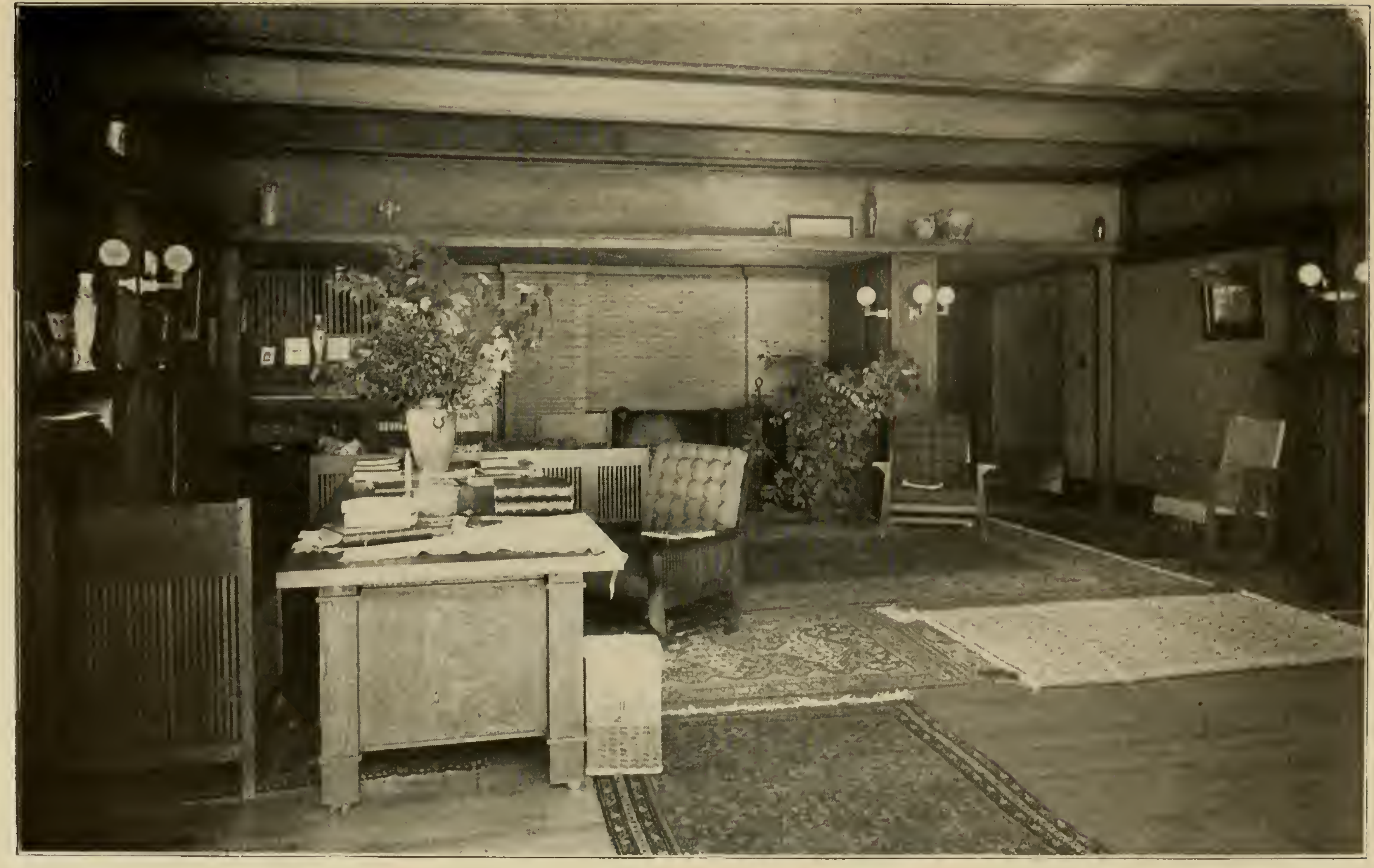
As a rule, wherever possible, it is wise to limit the length of each branch circuit to 100 feet; and the number and location of the distributing centers should be determined accordingly.

It may be found that it is sometimes necessary and even desirable to increase the limit of length. One instance of this may be found in hall or corridor lights in large buildings. It is generally desirable, in such cases, to control the hall lights from one point; and, as the number of lights at each outlet is generally small, it would not be economical to run mains for sub-centers of distribution. Hence, in instances of this character, the length of runs will frequently exceed the limit named. In the great majority of cases, however, the best results are obtained by limiting the runs to 90 or 100 feet.

There are several good reasons for placing such a limit on the length of a branch circuit. To begin with, assuming that we are going to place a limit on the loss in voltage (drop) from the switchboard to the lamp, it may be easily proven that up to a certain reasonable limit it is more economical to have a larger number of distributing centers and shorter branch circuits, than to have fewer centers and longer circuits. It is usual, in the better class of work, to limit the



ELECTRICAL KITCHEN IN EDISON BUILDING, CHICAGO



LIVING ROOM IN DWELLING FOR MR. W. W. WILLITS, HIGHLAND PARK, ILL.
Frank Lloyd Wright, Architect, Oak Park, Ill.
Brick of a Brown Color: Woodwork Stained Brown.

loss in voltage in any branch circuit to approximately one volt. Assuming this limit (one volt loss), it can readily be calculated that the number of lights at one outlet which may be connected on a branch circuit 100 feet long (using No. 14 B. & S. wire), is *four*; or in the case of outlets having a single light each, *five* outlets may be connected on the circuit, the first being 60 feet from the cut-out, the others being 10 feet apart.

These examples are selected simply to show that if the branch circuits are much longer than 100 feet, the loss must be increased to more than one volt, or else the number of lights that may be connected to one circuit must be reduced to a very small quantity, provided, of course, the size of the wire remains the same.

Either of these alternatives is objectionable—the first, on the score of regulation; and the second, from an economical standpoint. If, for instance, the loss in a branch circuit with all the lights turned on is four volts (assuming an extreme case), the voltage at which a lamp on that circuit burns will vary from four volts, depending on the number of lights burning at a time. This, of course, will cause the lamp to burn below candle-power when all the lamps are turned on, or else to diminish its life by burning above the proper voltage when it is the only lamp burning on the circuit. Then, too, if the drop in the branch circuits is increased, the sizes of the feeders and the mains must be correspondingly increased (if the total loss remains the same), thereby increasing their cost.

If the number of lights on the circuit is decreased, we do not use to good advantage the available carrying capacity of the wire.

Of course, one solution of the problem would be to increase the size of the wire for the branch circuits, thus reducing the drop. This, however, would not be desirable, except in certain cases where there were a few long circuits, such as for corridor lights or other special control circuits. In such instances as these, it would be better to increase the sizes of the branch circuit to No. 12 or even No. 10 B. & S. Gauge conductors, than to increase the number of centers of distribution for the sake of a few circuits only, in order to reduce the number of lamps (or loss) within the limit.

The method of calculating the loss in conductors has been given elsewhere; but it must be borne in mind, in calculating the loss of a branch circuit supplying more than one outlet, that separate calculations must be made for each portion of the circuit. That is, a calculation must be made for the loss to the first outlet, the length in this case being the distance from the center of distribution to the first outlet, and the load being the total number of lamps supplied by the circuit. The next step would be to obtain the loss between the first and second outlet, the length being the distance between the two outlets, and the load, in this case, being the total number of lamps supplied by the circuit, *minus* the number supplied by the first outlet; and so on. The loss for the total circuit would be the sum of these losses for the various portions of the circuit.

Feeders and Mains. If the building is more than one story, an elevation should be made showing the height and number of stories. On this elevation, the various distributing centers should be shown diagrammatically; and the current in amperes supplied through each center of distribution, should be indicated at each center. The next step is to lay out a tentative system of feeders and mains, and to ascertain the load in amperes supplied by each feeder and main. The estimated length of each feeder and main should then be determined, and calculation made for the loss from the switchboard to each center of distribution. It may be found that in some cases it will be necessary to change the arrangement of feeders or mains, or even the centers of distribution, in order to keep the total loss from the switchboard to the lamps within the limits previously determined. As a matter of fact, in important work, it is always best to lay out the entire work tentatively in a more or less crude fashion, according to the "cut and dried" method, in order to obtain the best results, because the entire layout may be modified after the first preliminary layout has been made. Of course, as one becomes more experienced and skilled in these matters, the final layout is often almost identical with the first preliminary arrangement.

TESTING

Where possible, two tests of the electric wiring equipment should be made, one after the wiring itself is entirely completed, and switches, cut-out panels, etc., are connected; and the second one after the fixtures have all been installed. The reason for this is that if a ground or short circuit is discovered before the fixtures are installed, it is more easily remedied; and secondly, because there is no division of the responsibility, as there might be if the first test were made only after the fixtures were installed. If the test shows no grounds or short circuits before the fixtures are installed, and one does develop after they are installed, the trouble, of course, is that the short circuit or ground is one or more of the fixtures. As a matter of fact, it is a wise plan always to make a separate test of each fixture after it is delivered at the building and before it is installed.

While a *magneto* is largely used for the purpose of testing, it is at best a crude and unreliable method. In the first place, it does not give an indication, even approximately, of the total insulation resistance, but merely indicates whether there is a ground or short circuit, or not. In some instances, moreover, a magneto test has led to serious errors, for reasons that will be explained. If, as is nearly always the case, the magneto is an alternating-current instrument, it may sometimes happen—particularly in long cables, and especially where there is a lead sheathing on the cable—that the magneto will ring, indicating to the uninitiated that there is a ground or short circuit on the cable. This may be, and usually is, far from being the case; and the cause of the ringing of the magneto is not a ground or short circuit, but is due to the capacity of the cable, which acts as a condenser under certain conditions, since the magneto producing an alternating current repeatedly charges and discharges the cable in opposite directions, this changing of the current causing the magneto to ring. Of course, this defect in a magneto could be remedied by using a commutator and changing it to a direct-current machine; but as the method is faulty in itself, it is hardly worth while to do this.

A portable *galvanometer* with a resistance box and Wheatstone bridge, is sometimes employed; but this method is objectionable because it requires a special instrument which cannot be used for many other purposes. Furthermore, it requires more skill and time to use than the *voltmeter* method, which will now be described.

The advantage of the voltmeter method is that it requires merely a direct-current voltmeter, which can be used for many other purposes, and which all engineers or contractors should possess, together with a box of cells having a potential of preferably over 30 volts. The voltmeter should have a scale of not over 150 volts, for the reason that if the scale on which the battery is used covers too wide a range (say 1,000 volts) the readings might be so small as to make the test inaccurate. A good arrangement would be to have a voltmeter having two scales—say, one of 60 and one of 600—which would make the voltmeter available for all practical potentials that are likely to be used inside of a building. If desired, a voltmeter could be obtained with three connections having three scales, the lowest scale of which would be used for testing insulation resistances.

Before starting a test, all of the fuses should be inserted and switches turned on, so that the complete test of the entire installation can be made. When this has been done, the voltmeter and battery should be connected, so as to obtain on the lowest scale of the voltmeter the electromotive force of the entire group of cells. This connection is shown in Fig. 33. Immediately after this has been done, the insulation resistance to be tested is placed in circuit, whether the insulation to be tested is a switchboard, slate panel-board, or the entire wiring installation; and the connections are made as shown in Fig. 34. A reading should then again be taken of the voltmeter; and the leakage is in proportion to the difference between the first and second readings of the voltmeter. The explanation given below will show how this resistance may be calculated: It is evident that the resistance in the first case was merely the resistance of the voltmeter and the internal resistance of the battery. As a rule, the internal resistance of the battery is so small in comparison with the resistance of the voltmeter and the external resistance, that it may be entirely neglected, and this will be done in the following calculation. In the second case, however, the total resistance in circuits is the resistance of the voltmeter and the battery, *plus* the entire insulation resistance on all the wires, etc., connected in circuit.

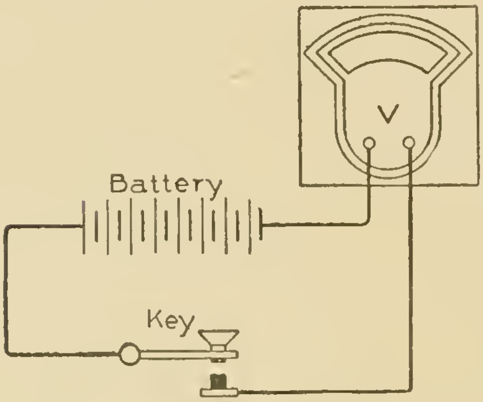


Fig. 33. Connections of Voltmeter and Battery for Testing Insulation Resistance.

To put this in mathematical form, the voltage of the cells may be indicated by the letter E; and the reading of the voltmeter when the insulation resistance is connected by the circuit, by the letter E'. Let R represent the resistance of the voltmeter and R_x represent the insulation resistance of the installation which we wish to measure.

It is a fact which the reader undoubtedly knows, that the E. M. F. as indicated by the voltmeter in Fig. 34 is inversely proportional to the resistance: that is, the greater the resistance, the lower will be the reading on the voltmeter, as this reading indicates the leakage or current passing through the resistance. Putting this in the shape of a formula, we have from the theory of proportion:

$$E : E' :: R + R_x : R \,;$$

or,

$$E' R + E' R_x = E R .$$

Transposing,

$$E' R_x = E R - E' R = R\,(E - E'),$$

and

$$R_x = \frac{R\,(E - E')}{E'} .$$

Or, expressed in words, the insulation resistance is equal to the resistance of the voltmeter *multiplied by* the difference between the first reading (or the voltage in the cells) and the second reading (or the reading of the voltmeter with the insulation resistance in series with the voltmeter), *divided by* this last reading of the voltmeter.

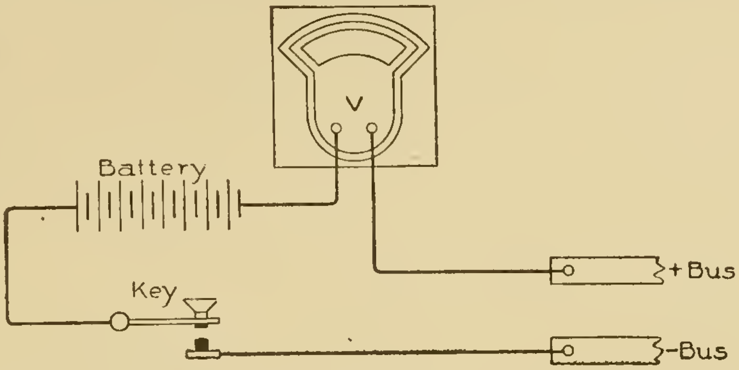


Fig. 34. Insulation Resistance Placed in Circuit, Ready for Testing.

Example. Assume a resistance of a voltmeter (R) of 20,000 ohms, and a voltage of the cells (E) of 30 volts; and suppose that the insulation resistance test of a wiring installation, including switchboard, feeders, branch circuits, panel-boards, etc., is to be made, the insulation resistance being represented by the letter R_x. By substituting in the formula

$$R_x = \frac{R\,(E - E')}{E'} ,$$

and assuming that the reading of the voltmeter with the insulation resistance connected is 5, we have:

$$R = \frac{20{,}000 \times (30-5)}{5} = 100{,}000 \text{ ohms.}$$

If the test shows an excessive amount of leakage, or a ground or short circuit, the location of the trouble may be determined by the process of elimination—that is, by cutting out the various feeders until the ground or leakage disappears, and, when the feeder on which the trouble exists has been located, by following the same process with the branch circuits.

Of course, the larger the installation and the longer and more numerous the circuits, the greater the leakage will be; and the lower will be the insulation resistance, as there is a greater surface exposed for leakage. The *Rules of the National Electric Code* give a sliding scale for the requirements as to insulation resistance, depending upon the amount of current carried by the various feeders, branch circuits, etc. The rule of the *National Electric Code* (No. 66) covering this point, is as follows:

> "The wiring in any building must test free from grounds; *i. e.*, the complete installation must have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) not less than that given in the following table:

Up to	5 amperes	4,000,000 ohms
"	10 "	2,000,000 "
"	25 "	800,000 "
"	50 "	400,000 "
"	100 "	200,000 "
"	200 "	100,000 "
"	400 "	50,000 "
"	800 "	25,000 "
"	1,600 "	12,500 "

> "The test must be made with all cut-outs and safety devices in place. If the lamp sockets, receptacles, electroliers, etc., are also connected, only one-half of the resistances specified in the table will be required."

ALTERNATING-CURRENT CIRCUITS

It is not within the province of this chapter to treat the various alternating-current phenomena, but simply to outline the modifications which should be made in designing and calculating electric light wiring, in order to make proper allowance for these phenomena.

The most marked difference between alternating and direct current, so far as wiring is concerned, is the effect produced by self-induction, which is characteristic of all alternating-current circuits. This self-induction varies greatly with conditions depending upon the arrangement of the circuit, the medium surrounding the circuit, the devices or apparatus supplied by or connected in the circuit, etc.

For example, if a coil having a resistance of 100 ohms is included in the circuit, a current of one ampere can be passed through the coil with an electric pressure of 100 volts, if direct current is used; while it might require a potential of several hundred volts to pass a current of one ampere if alternating-current were used, depending upon the number of turns in the coil, whether it is wound on iron or some other non-magnetic material, etc.

It will be seen from this example, that greater allowance should be made for self-induction in laying out and calculating alternating-current wiring, if the conditions are such that the self-induction will be appreciable.

On account of self-induction, the two wires of an alternating-current circuit must never be installed in separate iron or steel conduits, for the reason that such a circuit would be virtually a *choke coil* consisting of a single turn of wire wound on an iron core, and the self-induction would not only reduce the current passing through the circuit, but also might produce heating of the iron pipe. It is for this reason that the *National Electric Code* requires conductors constituting a given circuit to be placed in the same conduit, if that conduit is iron or steel, whenever the said circuit is intended to carry, or is liable to carry at some future time, an alternating current. This does not mean, in the case of a two-phase circuit, that all four conductors need be placed in the same conduit, but that the two conductors of a given phase must be placed in the same conduit. If, however, the three-wire system be used for a two-phase system, all three conductors should be placed in the same conduit, as should also be the case in a three-wire three-phase system. Of course, in a single-phase two- or three-wire system, the conductors should all be placed in the same conduit.

In calculating circuits carrying alternating current, no allowance usually should be made for self-induction when the conductors of the same circuit are placed close together in an iron conduit. When, however, the conductors are run exposed, or are separated from each other, calculation should be made to determine if the effects of self-induction are great enough to cause an appreciable inductive drop. There are several methods of calculating this drop due to self-induction—one by formula, and one by a mathematical method which will be described.

Skin Effect. Skin effect in alternating-current circuits is caused by an incorrect distribution of the current in the wire, the current tending to flow through the outer portion of the wire, it being a well-known fact that in alternating currents, the current density decreases toward the center of the conductor, and that in large wires, the current density at the center of the conductor is relatively quite small.

The skin effect increases in proportion to the square of the diameter, and also in direct ratio to the frequency of the alternating current.

For conductors of No. 0000 B. & S. Gauge, and smaller, and for frequencies of 60 cycles per second, or less, the skin effect is negligible and is less than one-half of one per cent.

For very large cables and for frequencies above 60 cycles per second, the skin effect may be appreciable; and in certain cases, allowance for it should be made in making the calculation. In ordinary practice, however, it may be neglected. Table IX, taken from *Alternating-Current Wiring and Distribution,* by W. R. Emmet, gives the data necessary for calculating the skin effect. The figures given in the first and third columns are obtained by multiplying the size of the conductor (in circular mils) by the frequency (number of cycles per second); and the figures in the second and fourth columns show the factor to be used in multiplying the ohmic resistance, in order to obtain the combined resistance and skin effect.

TABLE IX

Data for Calculating Skin Effect

Product of Circular Mils × Cycles per Sec.	Factor	Product of Circular Mils × Cycles per Sec.	Factor
10,000,000	1.00	70,000,000	1.13
20,000,000	1.01	80,000,000	1.17
30,000,000	1.03	90,000,000	1.20
40,000,000	1.05	100,000,000	1.25
50,000,000	1.08	125,000,000	1.34
60,000,000	1.10	150,000,000	1.43

The factors given in this table, *multiplied by* the resistance to direct currents, will give the resistance to alternating currents for copper conductors of circular cross-section.

Mutual Induction. When two or more circuits are run in the same vicinity, there is a possibility of one circuit inducing an electromotive force in the conductors of an adjoining circuit. This effect may result in raising or lowering the E. M. F. in the circuit in which a mutual induction takes place. The amount of this induced E. M. F. set up in one circuit by a parallel current, is dependent upon the current, the frequency, the lengths of the circuits running parallel to each other, and the relative positions of the conductors constituting the said circuits.

Under ordinary conditions, and except for long circuits carrying high potentials, the effect of mutual induction is so slight as to be negligible, unless the conductors are improperly arranged. In order to prevent mutual induction, the conductors constituting a given circuit should be grouped together. Figs. 35 to 39, inclusive, show five arrangements of two two-wire circuits; and show how relatively small the effect of first induction is when the conductors are properly arranged, as in Fig. 38, and how relatively large it may be when improperly arranged, as in Fig. 39. These diagrams are taken from a publication of Mr. Charles F. Scott, entitled *Polyphase Transmission*, issued by the Westinghouse Electric & Manufacturing Company.

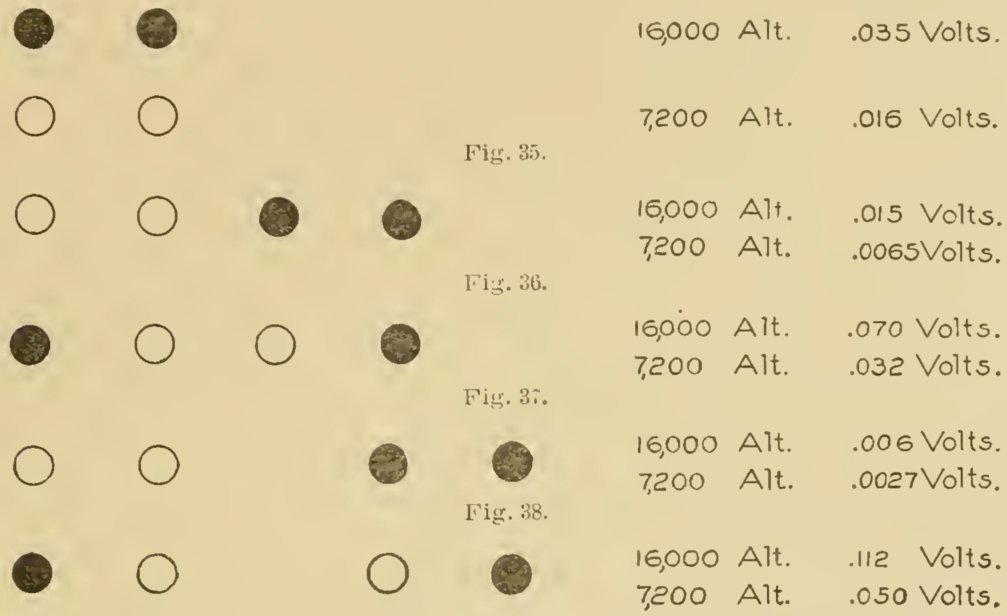


Fig. 35.

Fig. 36.

Fig. 37.

Fig. 38.

Fig. 39.

Various Groupings of Conductors in Two Two-Wire Circuits, Giving Various Effects of Induction.

Line Capacity. The effect of capacity is usually negligible, except in long transmission lines where high potentials are used; no calculations or allowance need be made for capacity, for ordinary circuits.

Calculation of Alternating-Current Circuits. In the instruction paper on "Power Stations and Transmission," a method is given for calculating alternating-current lines by means of formulæ, and data are given regarding power factor and the calculation of both single-phase and polyphase circuits. For short lines, secondary wiring, etc., however, it is probably more convenient to use the chart method devised by Mr. Ralph D. Mershon, described in the *American Electrician* of June, 1897, and partially reproduced as follows:

DROP IN ALTERNATING-CURRENT LINES

When alternating currents first came into use, when transmission distances were short and the only loads carried were lamps, the question of *drop* or *loss of voltage* in the transmitting line was a simple one, and the same methods as for direct current could without serious error be employed in dealing with it. The conditions existing in alternating practice to-day—longer distances, polyphase circuits, and loads made up partly or wholly of induction motors—render this question less simple; and direct-current methods applied to it do not lead to satisfactory results. Any treatment of this or of any engineering subject, if it is to benefit the majority of engineers, must not involve groping through long equations or complex diagrams in search of practical results. The results, if any, must be in available and convenient form. In what follows, the endeavor has been made to so treat the subject of drop in alternating-current lines that if the reader be grounded in the theory the brief space devoted to it will suffice; but if he do not comprehend or care to follow the simple theory involved, he may nevertheless turn the results to his practical advantage.

Calculation of Drop. Most of the matter heretofore published on the subject of drop treats only of the inter-relation of the E. M. F.'s involved, and, so far as the writer knows, there have not appeared in convenient form the data necessary for accurately calculating this quantity. Table X (page 47) and the chart (page 46) include, in a form suitable for the engineer's pocketbook, everything necessary for calculating the drop of alternating-current lines.

The chart is simply an extension of the vector diagram (Fig. 40), giving the relations of the E. M. F.'s of line, load and generator. In

Fig. 40, E is the generator E. M. F.; c, the E. M. F. impressed upon the load; c, that component of E which overcomes the back E. M. F. due to the impedance of the line. The component c is made up of two components at right angles to each other. One is a, the component overcoming the IR or back E. M. F. due to resistance of the line. The other is b, the component overcoming the reactance E. M. F. or back E. M. F. due to the alternating field set up around the wire by the current in the wire. The drop is the difference between E and c. It is d, the radial distance between two circular arcs, one of which is drawn with a radius c, and the other with a radius E.

The chart is made by striking a succession of circular arcs with O as a center. The radius of the smallest circle corresponds to c, the E. M. F. of the load, which is taken as 100 per cent. The radii of the succeeding circles increase by 1 per cent of that of the smallest circle; and, as the radius of the last or largest circle is 140 per cent of that of the smallest, the chart answers for drops up to 40 per cent of the E. M. F. delivered.

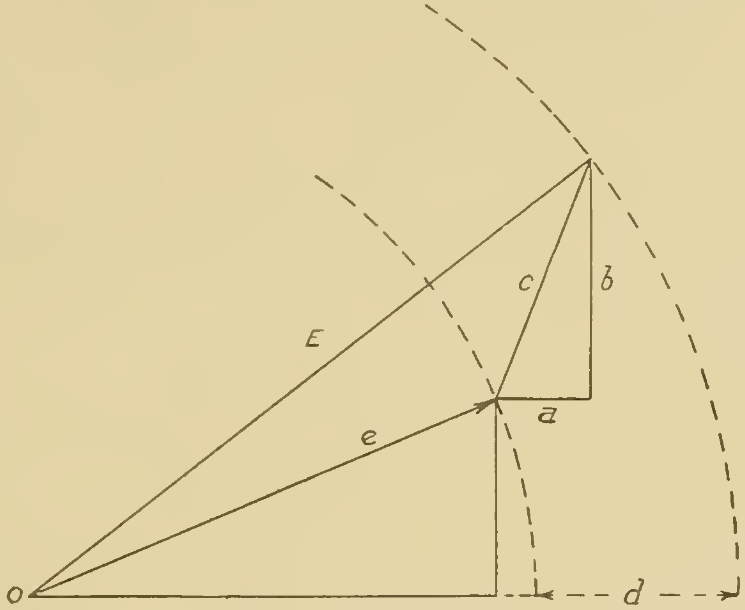


Fig. 40. Vector Diagram.

The terms *resistance volts, resistance E. M. F., reactance volts,* and *reactance E. M. F.*, refer, of course, to the voltages for overcoming the back E. M. F.'s due to resistance and reactance respectively. The figures given in the table under the heading "Resistance-Volts for One Ampere, etc." are simply the resistances of 2,000 feet of the various sizes of wire. The values given under the heading "Reactance-Volts, etc.," are, a part of them, calculated from tables published some time ago by Messrs. Houston and Kennelly. The remainder were obtained by using Maxwell's formula.

The explanation given in the table accompanying the chart

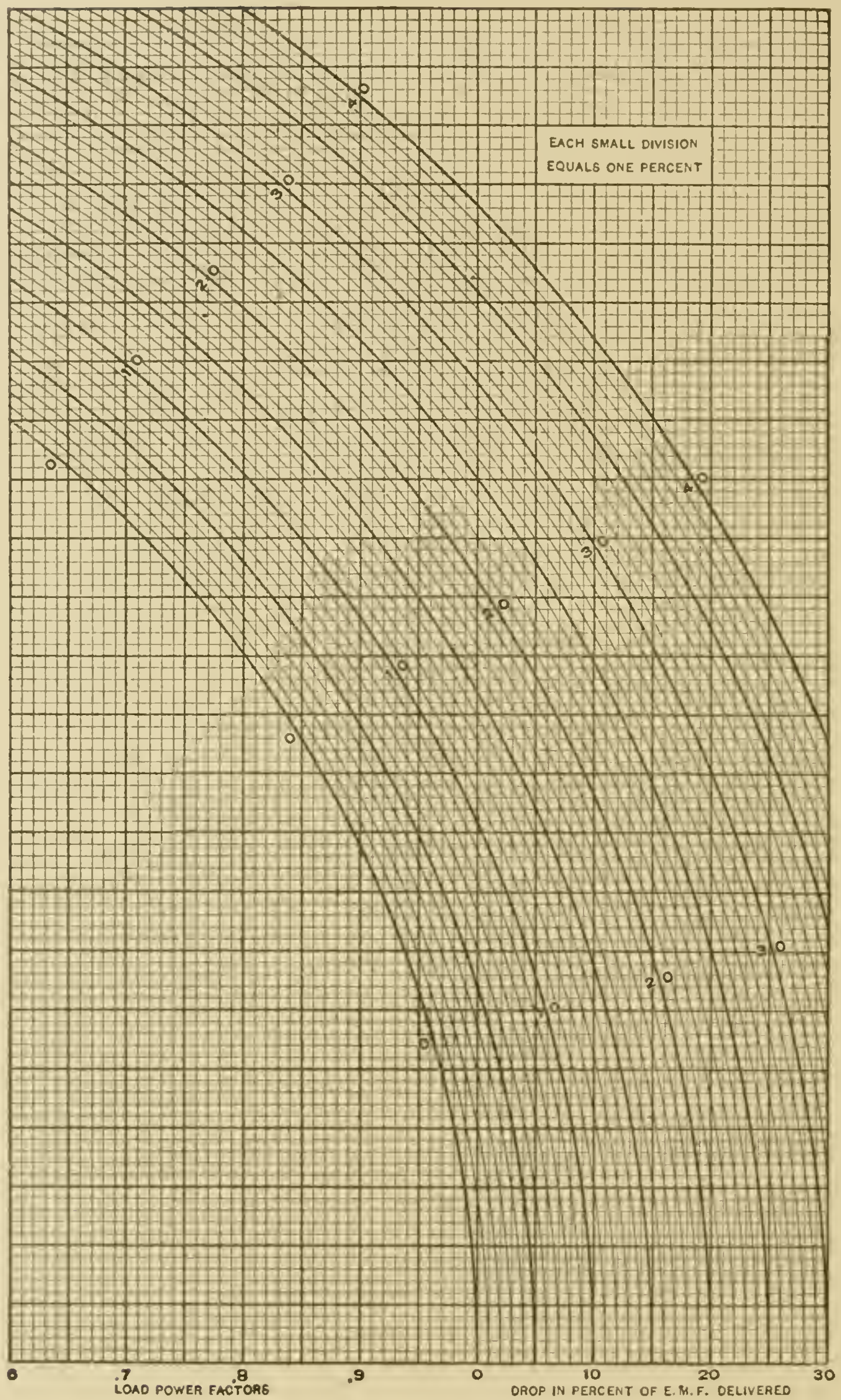


Chart for Calculating Drop in Alternating-Current Lines.

TABLE X

Data for Calculating Drop in Alternating-Current Lines

To be used in conjunction with Chart on opposite page.

By means of the table, calculate the *Resistance-Volts* and the *Reactance-Volts* in the line, and find what per cent each is of the E. M. F. delivered at the end of the line. Starting from the point on the chart where the vertical line corresponding with the power-factor of the load intersects the smallest circle, lay off in per cent the resistance E. M. F. horizontally and to the right; from the point thus obtained, lay off upward in per cent the reactance-E. M. F. The circle on which the last point falls gives the drop, in per cent, of the E. M. F. delivered at the end of the line. Every tenth circle arc is marked with the per cent drop to which it corresponds.

Throughout the table the lower figures in the squares give values for ONE MILE of line, corresponding to those of the upper figures for 1,000 feet of line.

Upper figures are REACTANCE-VOLTS in 1,000 ft. of Line (= 2,000 ft. of Wire) for One Ampere at 7,200 Alternations per Minute (60 Cycles per Second) for the distance given between Centers of Conductors.

Size of wire—B. & S.	Upper figures are Weight in Lbs. per 1,000 ft. Single Wire	Upper figures are RESISTANCE-VOLTS in 1,000 ft. of Line (2,000 ft. of wire) for One Ampere	½"	1"	2"	3"	6"	9"	12"	18"	24"	30"	36"
0000	639 3,376	.098 .518	.046 .243	.079 .417	.111 .586	.130 .687	.161 .850	.180 .951	.193 1.02	.212 1.12	.225 1.19	.235 1.24	.244 1.29
000	507 2,677	.124 .653	.052 .275	.085 .449	.116 .613	.135 .713	.167 .882	.185 .977	.199 1.05	.217 1.15	.230 1.22	.241 1.27	.249 1.32
00	402 2,123	.156 .824	.057 .301	.090 .475	.121 .639	.140 .739	.172 .908	.190 1.00	.204 1.08	.222 1.17	.236 1.25	.246 1.30	.254 1.34
0	319 1,685	.197 1.04	.063 .332	.095 .502	.127 .671	.145 .766	.177 .935	.196 1.04	.209 1.10	.228 1.20	.241 1.27	.251 1.33	.259 1.37
1	253 1,335	.248 1.31	.068 .359	.101 .533	.132 .687	.151 .797	.183 .966	.201 1.06	.214 1.13	.233 1.23	.246 1.30	.256 1.35	.265 1.40
2	201 1,059	.313 1.65	.074 .391	.106 .560	.138 .728	.156 .824	.188 .993	.206 1.09	.220 1.16	.238 1.26	.252 1.33	.262 1.38	.270 1.43
3	159 840	.394 2.08	.079 .417	.112 .591	.143 .755	.162 .856	.193 1.02	.212 1.12	.225 1.19	.244 1.29	.257 1.36	.267 1.41	.275 1.45
4	126 666	.497 2.63	.085 .449	.117 .618	.149 .787	.167 .882	.199 1.05	.217 1.15	.230 1.22	.249 1.32	.262 1.38	.272 1.44	.281 1.48
5	100 528	.627 3.31	.090 .475	.121 .639	.154 .813	.172 .908	.204 1.08	.223 1.18	.236 1.25	.254 1.34	.268 1.42	.278 1.47	.286 1.51
6	79 419	.791 4.18	.095 .502	.127 .671	.158 .834	.178 .940	.209 1.10	.228 1.20	.241 1.27	.260 1.37	.272 1.44	.283 1.49	.291 1.54
7	63 332	.997 5.27	.101 .533	.132 .697	.164 .866	.183 .966	.214 1.13	.233 1.23	.246 1.30	.265 1.40	.278 1.47	.288 1.52	.296 1.56
8	50 263	1.260 6.64	.106 .560	.138 .729	.169 .893	.188 .993	.220 1.16	.238 1.26	.252 1.33	.270 1.43	.284 1.50	.293 1.55	.302 1.60

(Table X) is thought to be a sufficient guide to its use, but a few examples may be of value.

Problem. Power to be delivered, 250 K.W.; E. M. F. to be delivered, 2,000 volts; distance of transmission, 10,000 feet; size of wire, No. 0; distance between wires, 18 inches; power factor of load, .8; frequency, 7,200 alternations per minute. Find the line loss and drop.

Remembering that the power factor is that fraction by which the apparent power of volt-amperes must be multiplied to give the true power, the apparent power to be delivered is

$$\frac{250\text{ K.W.}}{.8} = 312.5 \text{ apparent K.W.}$$

The current, therefore, at 2,000 volts will be

$$\frac{312{,}500}{2{,}000} = 156.25 \text{ amperes.}$$

From the table of reactances under the heading "18 inches," and corresponding to No. 0 wire, is obtained the constant .228. Bearing the instructions of the table in mind, the reactance-volts of this line are, 156.25 (amperes) × 10 (thousands of feet) × .228 = 356.3 volts, which is 17.8 per cent of the 2,000 volts to be delivered.

From the column headed "Resistance-Volts" and corresponding to No. 0 wire, is obtained the constant .197. The resistance-volts of the line are, therefore, 156.25 (amperes) × 10 (thousands of feet) × .197 = 307.8 volts, which is 15.4 per cent of the 2,000 volts to be delivered.

Starting, in accordance with the instructions of the table, from the point where the vertical line (which at the bottom of the chart is marked "Load Power Factor" .8) intersects the inner or smallest circle, lay off horizontally and to the right the resistance-E. M. F. in per cent (15.4); and *from the point thus obtained,* lay off vertically the reactance-E. M. F. in per cent (17.8). The last point falls at about 23 per cent, as given by the circular arcs. This, then, is the drop, in per cent, of *the E. M. F. delivered.* The drop, in per cent, of the *generator* E. M. F. is, of course,

$$\frac{23}{100+23} = 18.7 \text{ per cent.}$$

The percentage *loss of power* in the line has not, as with direct current, the same value as the percentage drop. This is due to the fact that the line has reactance, and also that the apparent power delivered to the load is not identical with the true power—that is, the load power factor is less than unity. The loss must be obtained by calculating $I^2 R$ for the line, or, what amounts to the same thing, by multiplying the resistance-volts by the current.

The resistance-volts in this case are 307.8, and the current 156.25 amperes. The loss is $307.8 \times 156.25 = 48.1$ K. W. The percentage *loss* is

$$\frac{48.1}{250 + 48.1} = 16.1 \text{ per cent.}$$

Therefore, for the problem taken, the *drop* is 18.7 per cent, and the *loss* is 16.1 per cent. If the problem be to find the size wire for a given drop, it must be solved by trial. Assume a size of wire and calculate the drop; the result in connection with the table will show the direction and extent of the change necessary in the size of wire to give the required drop.

The effect of the line reactance in increasing the drop should be noted. If there were no reactance, the drop in the above example would be given by the point obtained in laying off on the chart the resistance-E. M. F. (15.4) only. This point falls at 12.4 per cent, and the drop in terms of the generator E. M. F. would be

$$\frac{12.4}{112.4} = 11 \text{ per cent, instead of } 18.7 \text{ per cent.}$$

Anything therefore which will reduce reactance is desirable.

Reactance can be reduced in two ways. One of these is to diminish the distance between wires. The extent to which this can be carried is limited, in the case of a pole line, to the least distance at which the wires are safe from swinging together in the middle of the span; in inside wiring, by the danger from fire. The other way of reducing reactance is to split the copper up into a greater number of circuits, and arrange these circuits so that there is no inductive interaction. For instance, suppose that in the example worked out above, two No. 3 wires were used instead of one No. 0 wire. The resistance-volts would be practically the same, but the reactance-volts would be less in the ratio $\frac{1}{2} \times \frac{.244}{.228} = .535$, since each circuit would bear half the current the No. 0 circuit does, and the constant for No. 3 wire is .244, instead of .228—that for No. 0. The effect of subdividing the copper is also shown if in the example given it is desired to reduce the drop to, say, one-half. Increasing the copper from No. 0 to No. 0000 will not produce the required result, for, although the resistance-volts will be reduced one-half, the reactance-volts will be reduced only in the ratio $\frac{.212}{.228}$. If, however, *two* inductively independent circuits of No. 0 wire be used, the resistance- and reactance-volts will both be reduced one-half, and the drop will therefore be diminished the required amount.

The component of drop due to reactance is best diminished by subdividing the copper or by bringing the conductors closer together. It is little affected by change in size of conductors.

An idea of the manner in which changes of power factor affect drop is best gotten by an example. Assume distance of transmission, distance between conductors E. M. F., and frequency, the same as in the previous example. Assume the *apparent* power delivered the same as before, and let it be constant, but let the power factor be given several different values; the true power will therefore be a variable depending upon the value of the power factor. Let the size of wire be No. 0000. As the apparent power, and hence the current, is the same as before, and the line resistance is one-half, the resistance-E. M. F. will in this case be

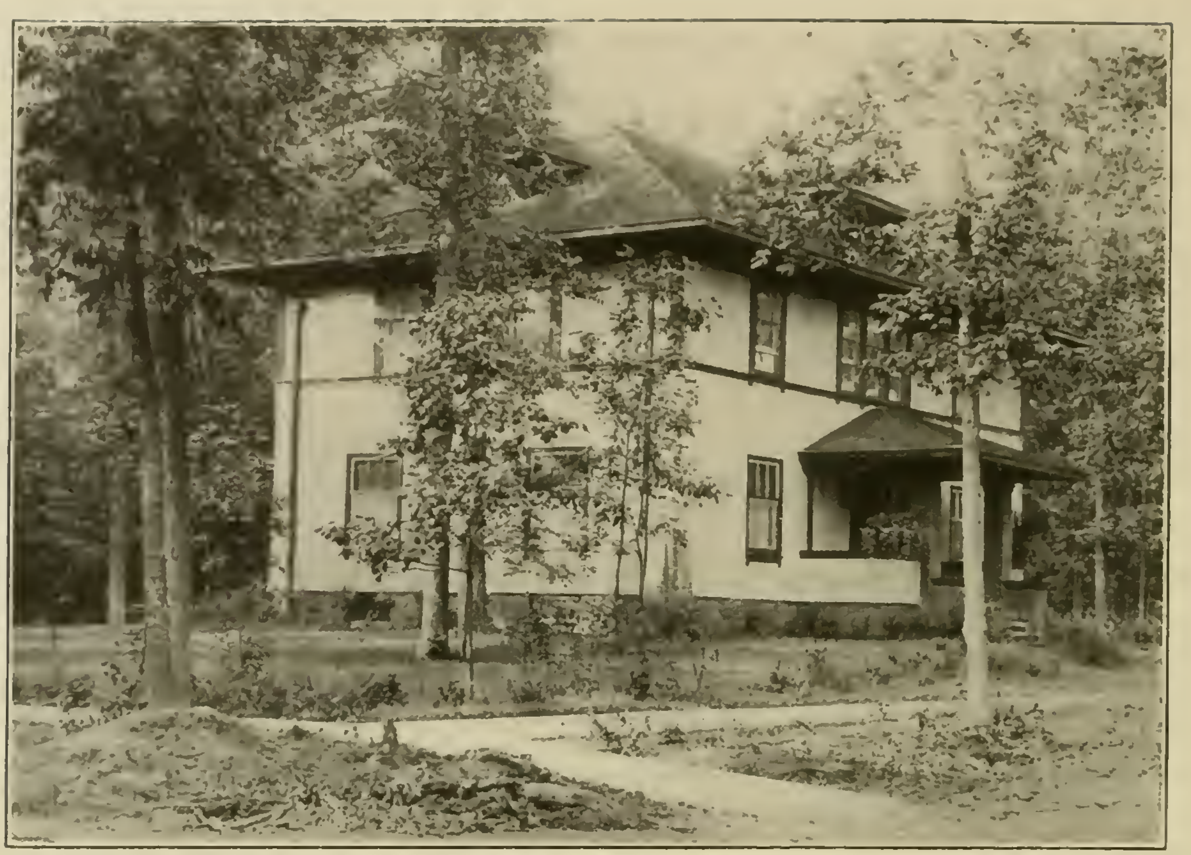
$$\frac{15.4}{2}, \text{ or } 7.7 \text{ per cent of the E. M. F. delivered.}$$

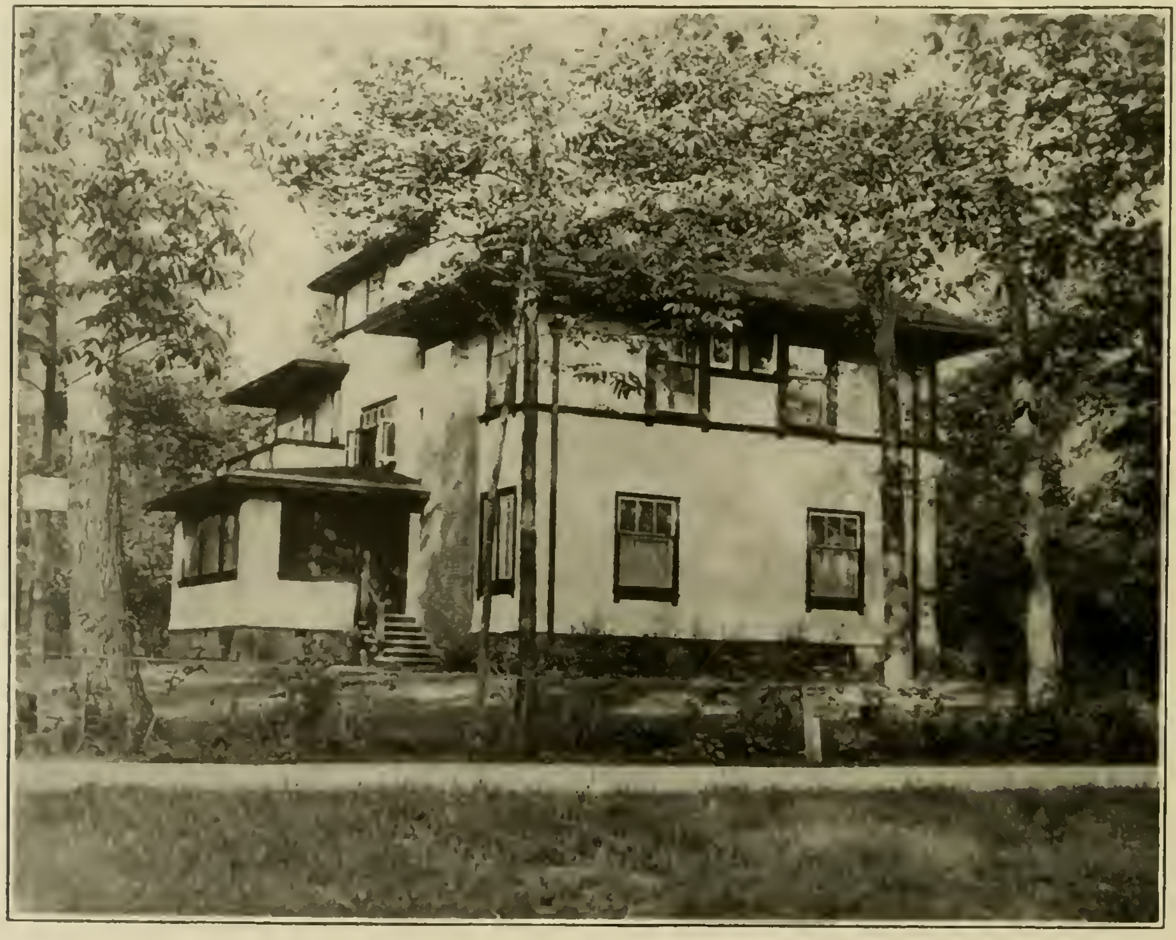
Also, the reactance-E. M. F. will be

$$\frac{.212 \times 17.8}{.228} = 16.5 \text{ per cent.}$$

Combining these on the chart for a power factor of .4, and deducing the drop, in per cent, of the generator E. M. F., the value obtained is 15.3 per cent; with a power factor of .8, the drop is 14 per cent; with a power factor of unity, it is 8 per cent. If in this example the *true* power, instead of the *apparent* power, had been taken as constant, it is evident that the values of drop would have differed more widely, since the current, and hence the resistance- and reactance-volts, would have increased as the power factor diminished. The condition taken more nearly represents that of practice.

If the line had resistance and no reactance, the several values of drop, instead of 15.3, 14, and 8, would be 3.2, 5.7, and 7.2 per cent respectively, showing that for a load of lamps the drop will not

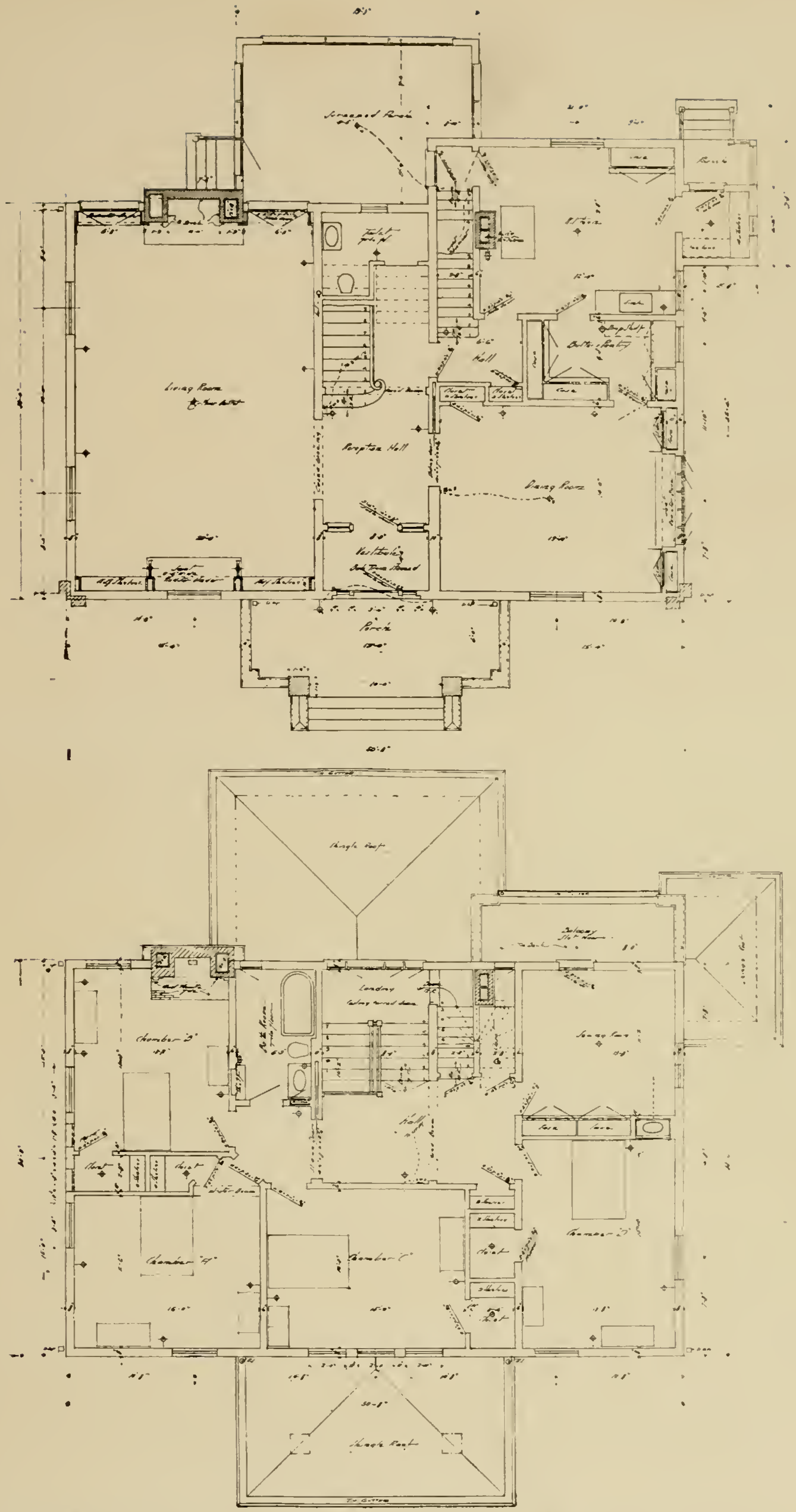




FRONT AND REAR VIEWS OF RESIDENCE FOR MR. PERCY B. ECKHART, KENILWORTH, ILL.

W. Carbys Zimmerman, Architect, Chicago, Ill.

Built in 1906. Cost, $10,000. Stud Walls with Plaster on Wire Lath. First and Second Story Plans Shown on Opposite Page.



FIRST AND SECOND STORY PLANS OF RESIDENCE FOR MR. PERCY B. ECKHART, KENILWORTH, ILL.
W. Carbys Zimmerman, Architect, Chicago, Ill.
Exteriors Shown on Opposite Page.

be much increased by reactance; but that with a load, such as induction motors, whose power factor is less than unity, care should be taken to keep the reactance as low as practicable. In all cases it is advisable to place conductors as close together as good practice will permit.

When there is a transformer in circuit, and it is desired to obtain the combined drop of transformer and line, it is necessary to know the resistance- and reactance-volts of the transformer. The resistance-volts of the combination of line and transformer are the sum of the resistance-volts of the line and the resistance-volts of the transformer. Similarly, the reactance-volts of the line and transformer are the sum of their respective reactance-volts. The resistance- and reactance-E. M. F.s of transformers may usually be obtained from the makers, and are ordinarily given in per cent.* These percentages express the values of the resistance- and reactance-E. M. F.'s when the transformer delivers its normal *full-load* current; and they express these values in terms of the normal *no-load* E. M. F. of the transformer.

Consider a transformer built for transformation between 1,000 and 100 volts. Suppose the resistance- and reactance-E. M. F.'s given are 2 per cent and 7 per cent respectively. Then the corresponding voltages when the transformer delivers full-load current, are 2 and 7 volts or 20 and 70 volts according as the line whose drop is required is connected to the low-voltage or high-voltage terminals. These values, 2—7 and 20—70, hold, no matter at what voltage the trans-

---

*When the required values cannot be obtained from the makers, they may be measured. Measure the resistance of both coils. If the line to be calculated is attached to the high-voltage terminals of the transformer, the equivalent resistance is that of the high-voltage coil, *plus* the resistance obtained by *increasing* in the square of the ratio of transformation the measured resistance of the low-voltage coil. That is, if the ratio of transformation is 10, the equivalent resistance referred to the high-voltage circuit is the resistance of the high-voltage coil, *plus* 100 times that of the low-voltage coil. This equivalent resistance multiplied by the high-voltage current gives the transformer resistance-volts referred to the high-voltage circuit. Similarly, the equivalent resistance referred to the low-voltage circuit is the resistance of the low-voltage coil, *plus* that of the high-voltage coil *reduced* in the square of the ratio of transformation. It follows, of course, from this, that the values of the resistance-volts referred to the two circuits bear to each other the ratio of transformation. To obtain the reactance-volts, short-circuit one coil of the transformer and measure the voltage necessary to force through the other coil its normal current at normal frequency. The result is, nearly enough, the reactance-volts. It makes no difference which coil is short-circuited, as the results obtained in one case will bear to those in the other the ratio of transformation. If a close value is desired, subtract from the square of the voltage reading the square of the *resistance*-volts, and take the square root of the difference as the reactance-volts.

former is operated, since they depend only upon the strength of current, providing it is of the normal frequency. If any other than the full-load current is drawn from the transformer, the reactance- and resistance-volts will be such a proportion of the values given above as the current flowing is of the full-load current. It may be noted, in passing, that when the resistance- and reactance-volts of a transformer are known, its regulation may be determined by making use of the chart in the same way as for a line having resistance and reactance.

As an illustration of the method of calculating the drop in a line and transformer, and also of the use of table and chart in calculating low-voltage mains, the following example is given:

Problem. A single-phase induction motor is to be supplied with 20 amperes at 200 volts; alternations, 7,200 per minute; power factor, .78. The distance from transformer to motor is 150 feet, and the line is No. 5 wire, 6 inches between centers of conductors. The transformer reduces in the ratio $\frac{2{,}000}{200}$, has a capacity of 25 amperes at 200 volts, and, when delivering this current and voltage, its resistance-E. M. F. is 2.5 per cent, its reactance-E. M. F. 5 per cent. Find the drop.

The reactance of 1,000 feet of circuit consisting of two No. 5 wires, 6 inches apart, is .204. The reactance-volts therefore are

$$.204 \times \frac{150}{1{,}000} \times 20 = .61 \text{ volts.}$$

The resistance-volts are

$$.627 \times \frac{150}{1{,}000} \times 20 = 1.88 \text{ volts.}$$

At 25 amperes, the resistance-volts of the transformer are 2.5 per cent of 200, or 5 volts. At 20 amperes, they are $\frac{20}{25}$ of this, or 4 volts. Similarly, the transformer reactance-volts at 25 amperes are 10, and at 20 amperes are 8 volts. The combined reactance-volts of transformer and line are $8 + .61 = 8.61$, which is 4.3 per cent of the 200 volts to be delivered. The combined resistance-volts are $1.88 + 4$, or 5.88, which is 2.94 per cent of the E. M. F. to be delivered. Combining these quantities on the chart with a power factor of .78, the drop is 5 per cent of the delivered E. M. F.,

$$\text{or } \frac{5}{105} = 4.8 \text{ per cent}$$

of the impressed E. M. F. The transformer must be supplied with

$$\frac{2,000}{.952} = 2,100 \text{ volts},$$

in order that 200 volts shall be delivered to the motor.

Table X (page 47) is made out for 7,200 alternations, but will answer for any other number if the values for reactance be changed in direct proportion to the change in alternations. For instance, for 16,000 alternations, multiply the reactances given by $\frac{16,000}{7,200}$. For other distances between centers of conductors, interpolate the values given in the table. As the reactance values for different sizes of wire change by a constant amount, the table can, if desired, be readily extended for larger or smaller conductors.

The table is based on the assumption of sine currents and E. M. F.'s. The best practice of to-day produces machines which so closely approximate this condition that results obtained by the above methods are well within the limits of practical requirements.

Polyphase Circuits. So far, single-phase circuits only have been dealt with. A simple extension of the methods given above adapts them to the calculation of polyphase circuits. A four-wire *quarter-phase* (two-phase) transmission may, so far as loss and regulation are concerned, be replaced by two single-phase circuits identical (as to size of wire, distance between wires, current, and E. M. F.) with the two circuits of the quarter-phase transmission, provided that in both cases there is no inductive interaction between circuits. Therefore, to calculate a four-wire, quarter-phase transmission, compute the single-phase circuit required to transmit one-half the power at the same voltage. The quarter-phase transmission will require two such circuits.

A three-wire, *three-phase* transmission, of which the conductors are symmetrically related, may, so far as loss and regulation are concerned, be replaced by two single-phase circuits having no inductive interaction, and identical with the three-phase line as to size, wire, and distance between wires. Therefore, to calculate a three-phase transmission, calculate a single-phase circuit to carry one-half the load at the same voltage. The three-phase transmission will require three wires of the size and distance between centers as obtained for the single-phase.

A three-wire, quarter-phase transmission may be calculated *exactly* as regards loss, and *approximately* as regards drop, in the same way as for three-phase. It is possible to exactly calculate the drop, but this involves a more complicated method than the approximate one. The error by this approximate method is generally small. It is possible, also, to get a somewhat less drop and loss with the same copper by proportioning the cross-section of the middle and outside wires of a three-wire, quarter-phase circuit to the currents they carry, instead of using three wires of the same size. The advantage, of course, is not great, and it will not be considered here.

WIRING AN OFFICE BUILDING

The building selected as a typical sample of a wiring installation is that of an office building located in Washington, D. C. The figures shown are reproductions of the plans actually used in installing the work.

The building consists of a basement and ten stories. It is of fireproof construction, having steel beams with terra-cotta flat arches. The main walls are of brick and the partition walls of terra-cotta blocks, finished with plaster. There is a space of approximately five inches between the top of the iron beams and the top of the finished floor, of which space about three inches was available for running the electric conduits. The flooring is of wood in the offices, but of concrete, mosaic, or tile in the basement, halls, toilet-rooms, etc.

The electric current supply is derived from the mains of the local illuminating company, the mains being brought into the front of the building and extending to a switchboard located near the center of the basement.

As the building is a very substantial fireproof structure, the only method of wiring considered was that in which the circuits would be installed in iron conduits.

Electric Current Supply. The electric current supply is direct current, two-wire for power, and three-wire for lighting, having a potential of 236 volts between the outside conductors, and 118 volts between the neutral and either outside conductor.

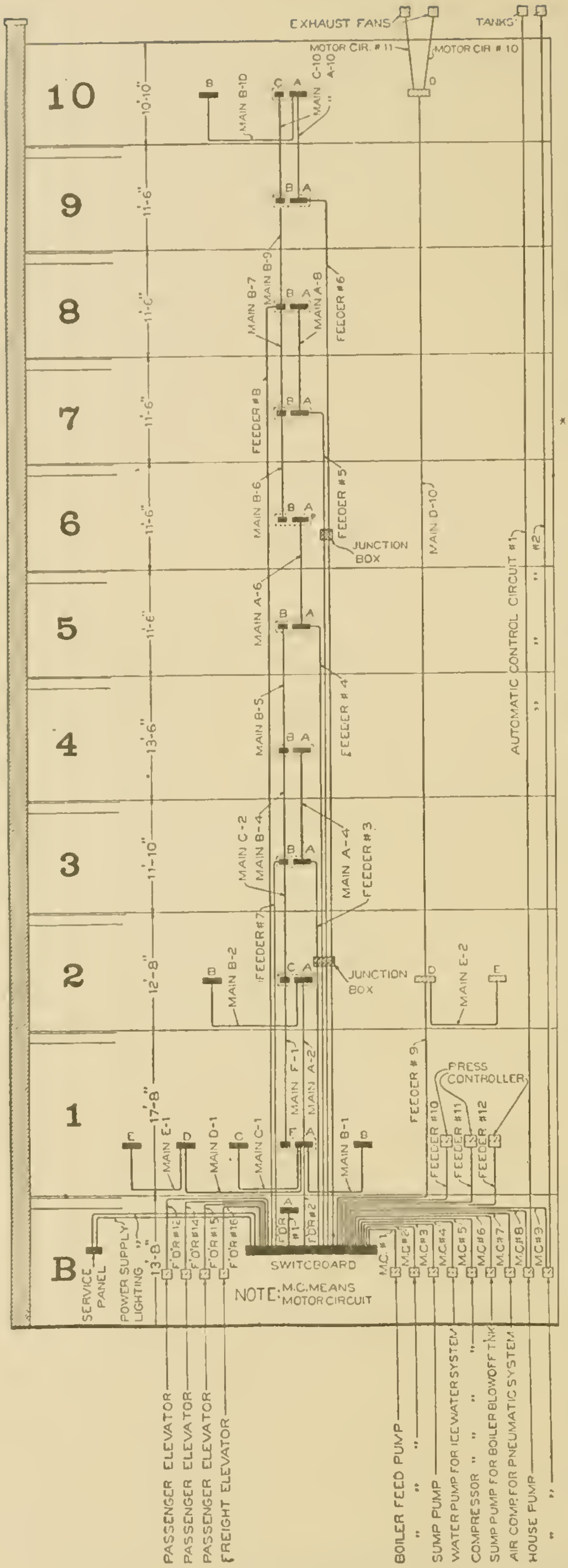
Switchboard. On the switchboard in the basement are mounted wattmeters, provided by the local electric company, and the various switches required for the control and operation of the lighting and power feeders. There are a total of ten triple-pole switches for lighting, and eighteen for power. An indicating voltmeter and ampere meter are also placed in the switchboard. A voltmeter is provided with a double-throw switch, and so arranged as to measure the potential across the two outside conductors, or between the neutral conductor and either of the outside conductors. The ampere meter is arranged with two shunts, one being placed in each outside leg; the shunts are connected with a double-pole, double-throw switch, so that the ampere meter can be connected to either shunt and thus measure the current supplied on each side of the system.

Character of Load. The building is occupied partly as a newspaper office, and there are several large presses in addition to the usual linotype machines, trimmers, shavers, cutters, saws, etc. There are also electrically-driven exhaust fans, house pumps, air-compressors, etc. The upper portion of the building is almost entirely devoted to offices rented to outside parties. The total number of motors supplied was 55; and the total number of outlets, 1,100, supplying 2,400 incandescent lamps and 4 arc lamps.

Feeders and Mains. The arrangement of the various feeders and mains, the cut-out centers, mains, etc., which they supply, are shown diagrammatically in Fig. 41, which also gives in schedule the sizes of feeders, mains, and motor circuits, and the data relating to the cut-out panels.

Although the current supply was to be taken from an outside source, yet, inasmuch as there was a probability of a plant being installed in the building itself at some future time, the three-wire system of feeders and mains was designed, with a neutral conductor equal to the combined capacity of the two outside conductors, so that 120-volt two-wire generators could be utilized without any change in the feeders.

Basement. The plan of the basement, Fig. 42, shows the branch circuit wiring for the outlets in the basement, and the location of the main switchboard. It also shows the trunk cables for the interconnection system serving to provide the necessary wires for telephones,



FEEDERS

NO.	END AT FLOOR	END AT CUT-OUT	BRANCH CIR.	LIGHTS	LENGHT-FT (ONE WAY)	LOSS IN VOLTS	SIZE OF WIRE NO. MIDDLE COND'R	SIZE OF WIRE NO. OUTSIDE COND'R	INSIDE DIA. OF CONDUIT ALLOWED *
1	BASMT	A	14	115	48	0.84	2	4	1.25"
2	1 ST	"	8	533	88	1.18	400000	4-0	2.5"
3	3 RD	"	43	248	119	1.68	4-0	0	2"
4	5 TH	"	44	296	147	1.78	250000	2-0	2.5"
5	7 TH	"	"	242	173	1.72	300000	3-0	"
6	9 TH	"	24	[illegible]	200	1.61	450000	250000	3"
7	3 RD	B	26	131	119	1.5	0	3	1.5"
8	8 TH	"	27	128	155	1.8	2-0	2	2"
L.S.	SW B	"		2165	138	1.5	4000000	2000000	***
9	2 ND	D			148		400000		3"
10	PRESS				83		700000		**
11	"				118		"		"
12	"				"		"		"
13	PASS ELV.				58		4-0		2"
14	"				"		"		"
15	"				"		"		"
16	FR'GT ELV				148		"		"
P.S.	SW B				138		2000000		****

* ALL CONDUCTORS IN ONE CONDUIT.
** SEPARATE CONDUIT FOR EACH CONDUCTOR
*** THIS FEEDER IS TO BE DIVIDED INTO FOUR (4)
" CONDUCTORS OF #2000000 C.M EACH.
" EACH CONDUCTOR IS TO BE INSTALLED IN A SEPARATE 3" (INSIDE DIAM.) CONDUIT
L.S.=LIGHTING SUPPLY
P.S.=POWER "
**** SEPARATE 3" (INSIDE DIAM.) CONDUIT FOR EACH
" CONDUCTOR

MAINS

MAINS	SUPPLIED BY FEEDER #	SUPPLIED BY CUT OUT	SUPPLIED BY FLOOR	LIGHTS	LENGTH-FT (ONE WAY)	LOSS IN VOLTS	SIZE OF WIRE NO. MIDDLE COND'R	SIZE OF WIRE NO. OUTSIDE COND'R	INSIDE DIA. OF CONDUIT ALLOWED *
A-2	2	A	1 ST	284	63	0.72	250000	2-0	2.5"
A-4	3	"	3 RD	147	18	0.41	2	4	1.25"
A-6	4	"	5 TH	146	"	0.4	"	"	"
A-8	5	"	7 TH	"	"	"	"	"	"
A-10	6	"	9 TH	171	"	0.23	0	3	1.5"
B-1	2	"	1 ST	76	70	0.51	"	"	"
B-2	"	"	"	206	58	0.58	4-0	0	2"
B-10	6	"	10 TH	87	44	0.37	0	3	1.5"
D-1	2	"	1 ST	120	12	0.22	2	4	1.25"
C-1	"	"	"	70	44	0.30	0	3	1.5"
F-1	7	C	2 ND	22	61	0.41	8	10	1"
C-2	"	B	3 RD	47	18	0.52	"	"	"
B-4	"	"	"	56	"	0.60	"	"	"
B-5	"	"	4 TH	28	"	0.31	"	"	"
B-6	8	"	7 TH	32	"	0.35	"	"	"
B-7	"	"	8 TH	56	"	0.60	"	"	"
B-9	"	"	"	44	"	0.43	"	"	"
C-10	"	"	9 TH	16	"	0.28	10	12	"
E-1	2	A	1 ST	61	92	0.86	2	4	1.25"
E-2	9	D	2 ND		84		0	0	1.5"
D-10	"	"	"		108		2	2	1.25"

* ALL CONDUCTORS IN ONE CONDUIT

MOTOR CIRCUITS

NO.	SUPPLIED BY FEEDER	SUPPLIED BY CUTOUT	SUPPLIED BY FLOOR	H.P. SUPPLIED	CURRENT IN AMP.	LENGTH IN FEET (ONE WAY)	SIZE OF WIRE	INSIDE DIAM. OF CONDUIT ALLOWED *
1			BSMT	15	60	74	2	1.25"
2			"	"	"	"	"	"
3			"	5	20	50	8	1"
4			"	"	"	40	"	"
5			"	15	60	"	2	1.25"
6			"	3	12	48	10	0.75"
7			"		20	"	8	1"
8			"	15	60	80	2	1.25"
9	MAIN		"	"	"	"	"	"
10	D-10	D	10 TH	7.5	30	134	6	1"
11	"	"	"	"	"	28	"	"

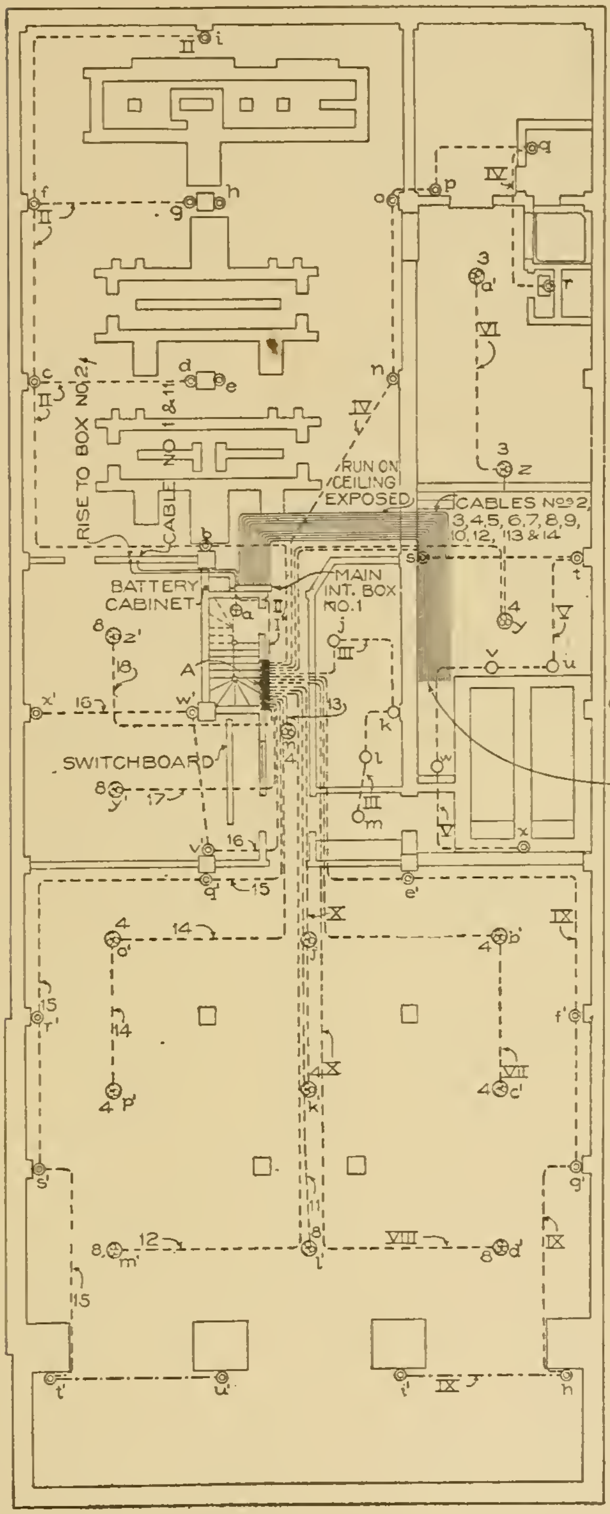
* BOTH CONDUCTORS IN ONE CONDUIT

CUT-OUTS

NAME	FLOOR	HAS CONNECTIONS FOR MAINS	BRANCH CIRCUITS	P.B. SWITCHES	METERS	KNIFE SWITCHES T.P.S.T. 25 AMP	50 "	100 "	150 "	200 "	D.P.S.T. 25 "	50 "	100 "	125 "	150 "
A	BSMT		20	10											
"	1 ST	4					2	1		1					
B	"		10	10											
C	"		"	"											
D	"	1	12	8			2								
E	"		"	4											
F	"		8	6											
A	2 ND	1	16	1			1*		1						
B	"		32	3											
C	"	1	4	4		2									
D	"	1									2		1	1	
E	"										4	6			
A	3 RD	1	22	1				2							
B	"	2	4	4		3									
A	4 TH		24	1											
B	"	1	4	4		2									
A	5 TH	1	24	1				2							
B	"		4	4											
A	6 TH		28	1											
B	"		4	4											
A	7 TH	1	24	1				2							
B	"	1	4	4		2									
A	8 TH		24	1											
B	"	2	4	4		3									
A	9 TH	1	24	1				1*	1						
B	"	1	4	4		2									
A	10 TH	1	24	1			1*	1							
B	"		16	1											
C	"		4	4											
D	"										4	2			

* MAIN SWITCH

Fig. 41. Wiring of an Office Building. Diagram Showing Arrangement of Feeders and Mains, Cut-Out Centers, etc.



SCHEDULE OF CIRCUITS

NO.	SUPPLIED by CUTOUT	SUPPLIED by MAIN	No. of BRANCHES	OUTLETS SUPPLIED	TOTAL OUTLETS	TOTAL LIGHTS	AT WHAT POINT CONTROLLED
I	A	FOR NO. 1	1	a	1	1	
II	"	"	3	bcdefghi	8	8	
III	"	"	1	jklm	4	4	
IV	"	"	1	nopqr	5	5	
V	"	"	1	stuvwx	6	6	
VI	"	"	1	yza'	3	10	S at A
VII	"	"	1	b'c'	2	8	" " "
VIII	"	"	1	d'	1	8	" " "
IX	"	"	1	e'f'g'h'i'	5	5	
X	"	"	1	j'k'	2	8	S at A
11	"	"	1	l'	1	8	" " "
12	"	"	1	m'	1	8	" " "
13	"	"	1	n'	1	4	" " "
14	"	"	1	o'p	2	8	" " "
15	"	"	1	q'r's't'u'	5	5	
16	"	"	1	v'w'x	3	3	
17	"	"	1	y'	1	8	S at A
18	"	"	1	z'	1	8	" " "
					52	115	

CABLE	NO. 2	RISES	TO	2nd	FLOOR
"	" 3	"	"	3rd	"
"	" 4	"	"	4th	"
"	" 5	"	"	5th	"
"	" 6	"	"	6th	"
"	" 7	"	"	7th	"
"	" 8	"	"	8th	"
"	" 9	"	"	9th	"
"	" 10	"	"	10th	"
"	" 12	"	"	2nd	"
"	" 13	"	"	5th	"
"	" 14	"	"	8th	"

Key Showing Explanation of Various Symbols used in Figs. 41 to 46 Inclusive

- --------Ceiling Chandelier
- --------Wall Bracket
- --------Gooseneck Bracket
- --------Wall Socket
- --------Drop Cord
- --------Arc Lamp
- --------Cooper-Hewitt Lamp
- --------Cluster
- --------Floor Outlet
- --------Desk Light
- --------Extension Outlet
- --------Push Button Switch
- --------Snap Switch
- --------Junction Box
- --------Electric Clock
- --------Master Clock
- --------Motor Starter
- --------Cut Out Panel
- --------Interconnection Box
- --------Power Panel
- --------Pull Box
- — — -----Circuit under Floor
- - - - - ----- " " above
- —·—·—----- " on Ceiling Exposed
- ———------Service Line under Floor

Fig. 42. Wiring an Office Building. Basement Plan Showing Branch Circuit Wiring for Outlets in Basement. Location of Main Switchboard, and Trunk Cables of the Interconnection System Providing Wires for Telephone, Ticker, and Messenger Call Service, etc,

tickers, messenger calls, etc., in all the rooms throughout the building, as will be described later.

To avoid confusion, the feeders were not shown on the basement plan, but were described in detail in the specification, and installed in accordance with directions issued at the time of installation. The electric current supply enters the building at the front, and a service switch and cut-out are placed on the front wall. From this point, a two-wire feeder for power and a three-wire feeder for lighting, are run to the main switchboard located near the center of the basement. Owing to the size of the conduits required for these supply feeders, as well as the main feeders extending to the upper floors of the building, the said conduits are run exposed on substantial hangers suspended from the basement ceiling.

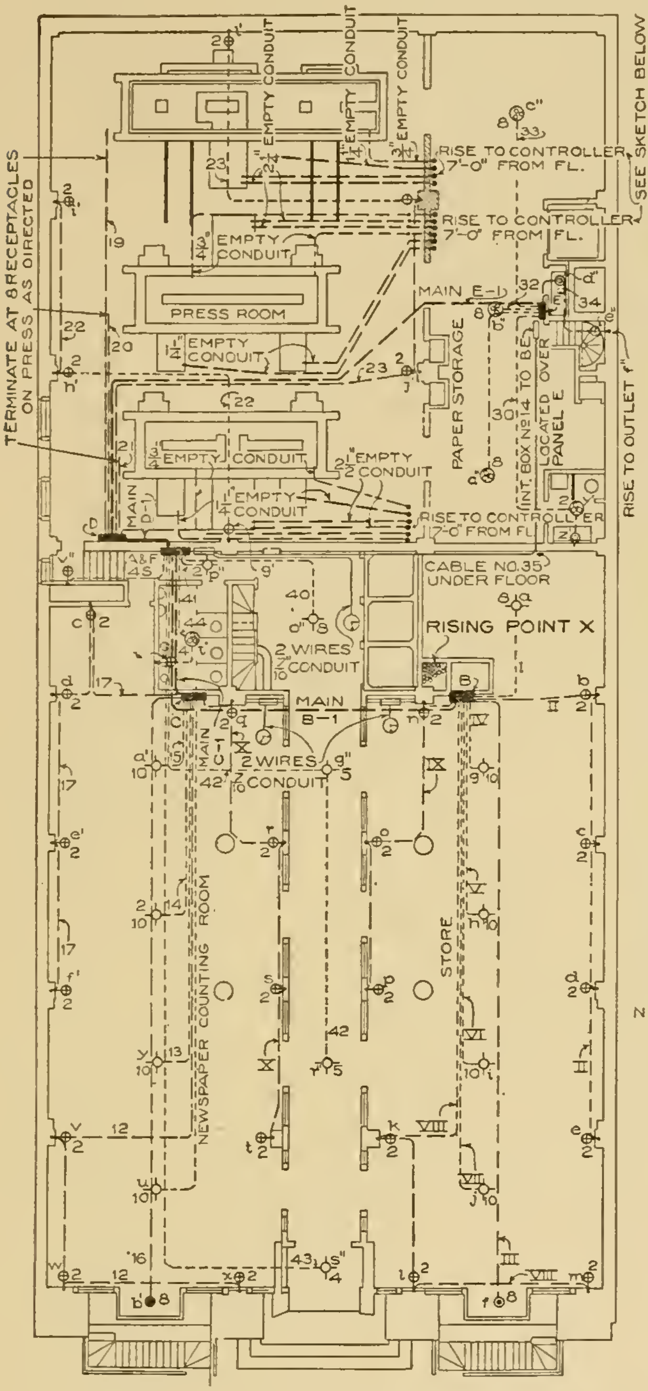
First Floor. The rear portion of the building from the basement through the first floor, Fig. 43, and including the mezzanine floor, between the first and second floors, at the rear portion of the building only, is utilized as a press room for several large and heavy, modern newspaper presses. The motors and controllers for these presses are located on the first floor. A separate feeder for each of these press motors is run directly from the main switchboard to the motor controller in each case. Empty conduits were provided, extending from the controllers to the motor in each case, intended for the various control wires installed by the contractor for the press equipments.

One-half of the front portion of the first floor is utilized as a newspaper office; the remaining half, as a bank.

Second Floor. The rear portion of the second floor, Fig. 44, is occupied as a composing and linotype room, and is illuminated chiefly by means of drop-cords from outlets located over the linotype machines and over the compositors' cases. Separate ⅛-horse-power motors are provided for each linotype machine, the circuits for the same being run underneath the floor.

Upper Floors. A typical plan (Fig. 45) is shown of the upper floors, as they are similar in all respects with the exception of certain changes in partitions, which are not material for the purpose of illustration or for practical example. The circuit work is sufficiently intelligible from the plan to require no further explanation.

Interconnection System. Fig. 46 is a diagram of the interconnection system, showing the main interconnection box located in the



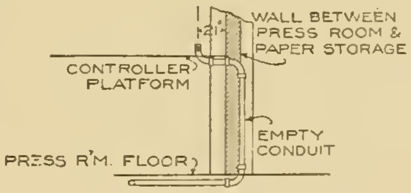
NOTE: ALL CONDUITS FOR THE PRESSES MUST COME THROUGH THE CONTROLLER PLATFORM 21" FROM THE WALL.

ALL CONDUITS ARE TO TERMINATE IN PRESS AS DIRECTED.

SCHEDULE OF CIRCUITS

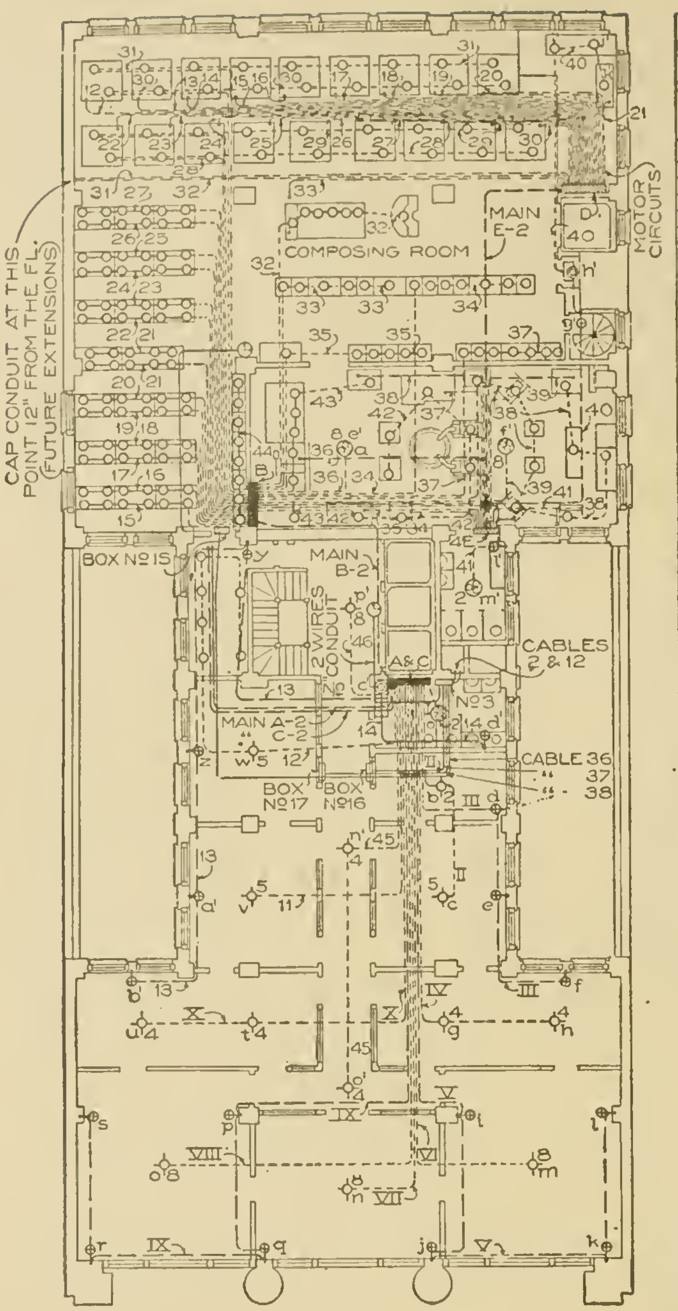
NO.	SUPPLIED		No. of BRANCHES	OUTLETS SUPPLIED	TOTAL		AT WHAT POINT CONTROLLED
	by CUTOUT	by MAIN			OUTLETS	LIGHTS	
I	B	F'D'R No. 2	1	a	1	8	S at B
II	"	"	1	bcde	4	8	" " "
III	"	"	1	f	1	8	" " "
IV	"	"	1	g	1	10	" " "
V	"	"	1	h	1	10	" " "
VI	"	"	1	i	1	10	" " "
VII	"	"	1	j	1	10	" " "
VIII	"	"	1	klm	3	6	" " "
IX	"	"	1	nop	3	6	" " "
			1		16	76	
X	C	C-1	1	qrst	4	8	S at C
11	"	"	1	u	1	10	" " "
12	"	"	1	vwx	3	6	" " "
13	"	"	1	y	1	10	" " "
14	"	"	1	z	1	10	" " "
15	"	"	1	a'	1	10	" " "
16	"	"	1	b'	1	8	" " "
17	"	"	1	c'd'e'f'	4	8	" " "
					16	70	
19	D	D-1	1	8 Receptacles	8	8	
20	"	"	1		8	8	
21	"	"	1		8	8	
22	"	"	1	g'h'i'	3	6	S at D
23	"	"	1	j'k'l'	3	6	" " "
24							
25							
26	SEE MEZZ. PLAN						
27							
28							
29							
30	E	E-1	1	y'z'	2	3	S at E
31	"	"	1	a"	1	8	" " "
32	"	"	1	b"	1	8	" " "
33	"	"	1	c"	1	8	" " "
34	"	"	1	d"e"f", g",	4	4	" " "
35							
36							
37	SEE MEZZ. PLAN						
38							
39							
40	F		1	o"	1	8	S at F
41	"	"	1	p"	1	2	" " "
42	"	"	1	q"r"	2	10	" " "
43	"	"	1	s"	1	4	" " "
44	"	"	1	t"u"	2	6	" " "
45	"	"	1	v"	1	1	" " "
					8	31	" " "

NOTE: THE CLOCKS IN STORE AND COUNTING ROOM ARE TO BE LOCATED AS DIRECTED BY ARCHITECT.



SKETCH SHOWING ROUTE OF EMPTY CONDUITS RISING TO CONTROLLER PLATFORM IN PRESS ROOM.

Fig. 43. Wiring of an Office Building.
First-Floor Plan, Showing Press Room in Rear, Containing Motors and Controllers for Newspaper Presses, Fed Directly from Main Switchboard in Basement; also, in front, Newspaper Counting Room and Bank Offices.



SCHEDULE OF CIRCUITS

NO.	SUPPLIED by CUTOUT	SUPPLIED by MAIN	Nº of BRANCHES	OUTLETS SUPPLIED	TOTAL OUTLETS	TOTAL LIGHTS	AT WHAT POINT CONTROLLED
I	A	A-2	1	a	1	2	S at A
II	"	"	1	b c	2	7	
III	"	"	1	d e f	3	3	
IV	"	"	1	g h	2	8	
V	"	"	1	i j k l	4	4	
VI	"	"	1	m	1	8	
VII	"	"	1	n	"	"	
VIII	"	"	1	o	"	"	
IX	"	"	1	p q r s	4	4	
X	"	"	1	t u	2	8	
11	"	"	1	v	1	5	
12	"	"	1	w & 6 Drop Cds	7	11	
13	"	"	1	y z a' b'	4	4	
14	"	"	1	c' d'	2	2	
					30	78	
15	B	B-2	1	Drop Cords	6	6	
16	"	"	1	" "	"	"	
17	"	"	1	" "	"	"	
18	"	"	1	" "	"	"	
19	"	"	1	" "	"	"	
20	"	"	1	" "	"	"	
21	"	"	1	" "	10	10	
22	"	"	1	" "	6	6	
23	"	"	1	" "	"	"	
24	"	"	1	" "	"	"	
25	"	"	1	" "	"	"	
26	"	"	1	" "	"	"	
27	"	"	1	" "	"	"	
28	"	"	1	" "	9	9	
29	"	"	1	" "	"	"	
30	"	"	1	" "	"	"	
31	"	"	1	" "	"	"	
32	"	"	1	" "	7	7	
33	"	"	1	" "	6	6	
34	"	"	1	" "	7	7	
35	"	"	1	" "	6	6	
36	"	"	1	e'	1	8	S at B
37	"	"	1	Drop Cords	7	7	
38	"	"	1	" "	9	9	
39	"	"	1	f'	1	8	S at B
40	"	"	1	g' h' i' j' k'	5	5	
41	"	"	1	l' m'	2	3	S at B
42	"	"	1	Drop Cords	7	7	
43	"	"	1	" "	7	7	
44	"	"	1	" "	8	8	
45	C	C-2	1	n' o'	2	8	S at C
46	"	"	1	p'	1	8	" " "

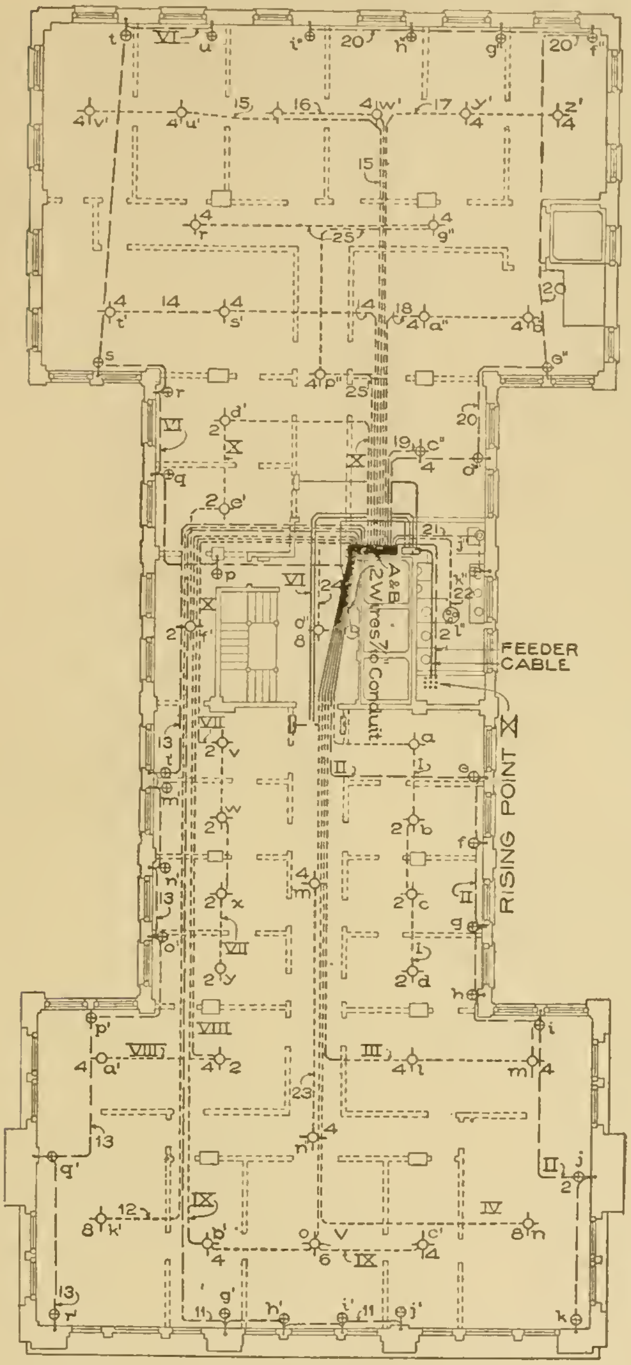
TERMINATE ALL MOTOR CIRCUITS AT MOTOR CONTROLLER AS DIRECTED

MOTOR CIRCUITS

NO.	SUPPLIED BY FEEDER NO.	SUPPLIED BY CUT-OUT	SUPPLIED BY FLOOR	H.P. SUPPLIED	CURRENT IN AMPERES	LENGTH IN FT. (ONE WAY)	SIZE OF WIRE	INSIDE DIA. OF CONDUIT ALLOWED *
12	9	D	2ND	* *		98	10	$\frac{3}{4}$"
13	"	"	"	"		90	"	"
14	"	"	"	"		82	"	"
15	"	"	"	"		76	"	"
16	"	"	"	"		68	"	"
17	"	"	"	"		60	"	"
18	"	"	"	"		52	"	"
19	"	"	"	"		46	"	"
20	"	"	"	"		38	"	"
21	"	"	"	"		28	"	"
22	"	"	"	"		94	"	"
23	"	"	"	"		86	"	"
24	"	"	"	"		78	"	"
25	"	"	"	"		70	"	"
26	"	"	"	"		62	"	"
27	"	"	"	"		54	"	"
28	"	"	"	"		46	"	"
29	"	"	"	"		38	"	"
30	"	"	"	"		30	"	"
31	"	"	"	"		90	"	"
32	"	"	"	"		"	"	"
33	"	"	"	$\frac{1}{2}$		82	"	"
34	"	E	"	3		28	"	"
35	"	"	"	"		32	"	"
36	"	"	"	"		52	"	"
37	"	"	"	"		34	"	"
38	"	"	"	1		48	12	"
39	"	"	"	2		46	10	"
40	"	"	"	3		30	"	"
41	"	"	"	2		28	"	"
42	"	"	"	3		18	"	"

* BOTH CONDUCTORS IN ONE CONDUIT
** $\frac{1}{2}$H.P. REDUCED TO $\frac{1}{4}$ H.P.

Fig. 41. Wiring of an Office Building. Plan of Second Floor. Rear Portion Occupied as a Composing and Linotype Room.

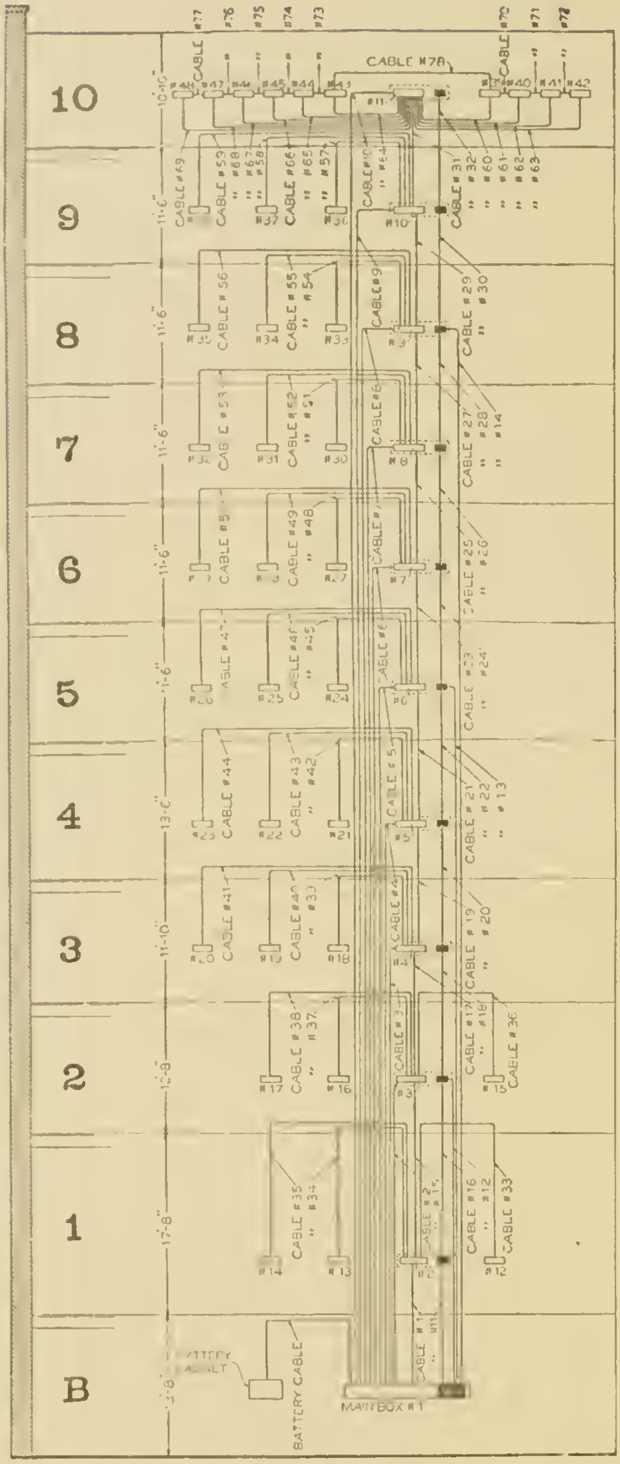


SCHEDULE OF CIRCUITS

NO.	SUPPLIED		Nº of BRANCHES	OUTLETS SUPPLIED	TOTAL		AT WHAT POINT CONTROLLED
	by CUTOUT	by MAIN			OUTLETS	LIGHTS	
I	A		1	abcd	4	8	
II	"	"	1	efghijk	7	7	
III	"	"	1	lm	2	8	
IV	"	"	1	n	1	8	
V	"	"	1	o	1	6	
VI	"	"	1	pqrstu	6	6	
VII	"	"	1	vwxy	4	8	
VIII	"	"	1	z a'	2	8	
IX	"	"	1	b'c'	2	8	
X	"	"	1	d'e'f'	3	6	
11	"	"	1	g'h'i'j'	4	4	
12	"	"	1	k'	1	8	
13	"	"	1	l'm'n'o'p'q'r'	7	7	
14	"	"	1	s't'	2	8	
15	"	"	1	u'v'	2	8	
16	"	"	1	w'x'	2	8	
17	"	"	1	y'z'	2	8	
18	"	"	1	a"b"	2	8	
19	"	"	1	c"	1	4	
20	"	"	1	d"e"f"g"h"i"	6	6	
21	"	"	1	j"k"	2	2	
22	"	"	1	l"	1	2	S at A
					64	146	
23	B		1	m"n"	2	8	S at B
24	"	"	1	o"	1	8	S " "
25	"	"	1	p"q"r"	3	12	S " "
					6	28	

Fig. 45. Wiring of an Office Building.

Typical Plan of Upper Floors, Showing Circuit Work, Schedule, etc. All the Floors above the Second are Similar to One Another in Plan, Differing Only in Comparatively Unimportant Details of Partitions.



— CABLES.—

NO.	START AT BOX NO.	START AT FLOOR	END AT BOX NO.	END AT FLOOR	NO. OF WIRES	LENGTH IN FEET	INSIDE DIA. of CONDUIT ALLOWED
1	1	BASMT	2	1 ST	50	122	1½"
2	"	"	3	2 ND	"	116	"
3	"	"	4	3 RD	"	128	"
4	"	"	5	4 TH	"	132	"
5	"	"	6	5 TH	"	154	"
6	"	"	7	6 TH	"	165	"
7	"	"	8	7 TH	"	176	"
8	"	"	9	8 TH	"	187	"
9	"	"	10	9 TH	"	208	"
10	"	"	11	10 TH	"	219	"
11	"	"	2	1 ST	10	122	1"
12	"	"	3	2 ND	"	116	"
13	"	"	6	5 TH	"	154	"
14	"	"	9	8 TH	"	187	"
15	2	1 ST	3	2 ND	"	22	1"
16	"	"	"	"	"	"	1½"
17	3	2 ND	4	3 RD	"	16	1"
18	"	"	"	"	"	"	1½"
19	4	3 RD	5	4 TH	"	15	1"
20	"	"	"	"	"	"	1½"
21	5	4 TH	6	5 TH	"	"	1"
22	"	"	"	"	"	"	1½"
23	6	5 TH	7	6 TH	"	"	1"
24	"	"	"	"	"	"	1½"
25	7	6 TH	8	7 TH	"	"	1"
26	"	"	"	"	"	"	1½"
27	8	7 TH	9	8 TH	"	"	1"
28	"	"	"	"	"	"	1½"
29	9	8 TH	10	9 TH	"	"	1"
30	"	"	"	"	"	"	1½"
31	10	9 TH	11	10 TH	"	"	1"
32	"	"	"	"	"	"	1½"
33	2	1 ST	12	1 ST	"	61	1"
34	"	"	13	"	"	22	"
35	"	"	14	"	"	84	"
36	3	2 ND	15	2 ND	"	[illegible]	"
37	"	"	16	"	"	28	"
38	"	"	17	"	"	22	"
39	4	3 RD	18	3 RD	"	[illegible]	"
40	"	"	19	"	"	53	"
41	"	"	20	"	"	[illegible]	"
42	5	4 TH	[illegible]	4 TH	"	[illegible]	"
43	"	"	22	"	"	[illegible]	"
44	"	"	23	"	"	51	"
45	6	5 TH	24	[illegible]	"	[illegible]	"
46	"	"	25	"	[illegible]	53	1½"
47	"	"	26	"	[illegible]	[illegible]	[illegible]
48	7	6 TH	27	[illegible]	"	[illegible]	"
49	"	"	28	"	"	[illegible]	"
50	"	"	29	"	"	51	"
51	8	7 TH	30	[illegible]	"	[illegible]	"
52	"	"	31	"	"	53	"
53	"	"	[illegible]	"	"	[illegible]	"
54	[illegible]	[illegible]	33	[illegible]	"	[illegible]	"
55	"	"	[illegible]	"	"	[illegible]	"
56	"	"	[illegible]	"	"	[illegible]	"
57	10	9 TH	36	[illegible]	"	[illegible]	"
58	"	"	37	"	"	[illegible]	"
59	"	"	38	"	"	51	"
60	11	10 TH	[illegible]	10 TH	"	[illegible]	"
61	"	"	[illegible]	"	"	[illegible]	"
62	"	"	41	"	"	[illegible]	"
63	"	"	42	"	"	[illegible]	"
64	"	"	43	"	"	40	"
65	"	"	44	"	"	[illegible]	"
66	"	"	[illegible]	"	"	[illegible]	"
67	"	"	46	"	"	[illegible]	"
68	"	"	47	"	"	75	"
69	"	"	48	"	"	[illegible]	"
70	39	"	[illegible]	"	[illegible]	11	"
71	[illegible]	"	41	"	"	[illegible]	"
72	41	"	42	"	"	13	"
73	43	"	44	"	"	[illegible]	"
74	44	"	[illegible]	"	"	[illegible]	"
75	[illegible]	"	[illegible]	"	"	"	"
76	[illegible]	"	47	"	"	"	"
77	[illegible]	"	48	"	"	"	"
78	[illegible]	"	43	"	"	"	"

* EMPTY CONDUIT ONLY

— BOXES.—

NO.	FLOOR	NO. REQUIRED OF VARIOUS SIZES: 60 F	1-A	14-B	16-B	20-B	2-B	3-A				
1	BASMT	1										
2	1 ST			1								
3	2 ND				1							
4	3 RD			1								
5	4 TH			1								
6	5 TH				1							
7	6 TH			1								
8	7 TH			1								
9	8 TH				1							
10	9 TH			1								
11	10 TH					1						
12	1 ST						1					
13	"						1					
14	"						1					
15	2 ND						1					
16	"						1					
17	"						1					
18	3 RD						1					
19	"						1					
20	"						1					
21	4 TH						1					
22	"						1					
23	"						1					
24	5 TH						1					
25	"						1					
26	"						1					
27	6 TH						1					
28	"						1					
29	"						1					
30	7 TH						1					
31	"						1					
32	"						1					
33	8 TH						1					
34	"						1					
35	"						1					
36	9 TH						1					
37	"						1					
38	"						1					
39	10 TH		1									
40	"		1									
41	"		1									
42	"		1									
43	"		1									
44	"		1									
45	"		1									
46	"							1				
47	"		1									
48	"		1									
TOTALS		1	9	6	3	1	27	1				

— FIXTURES. —

LOCATION	BATTERIES	BATTERY CABINET	CLOCKS	MASTER CLOCK								
BASMT	8	1										
1 ST FL			[illegible]									
[illegible]			[illegible]									
[illegible]			[illegible]									
4 TH "			[illegible]									
[illegible]			[illegible]									
6 TH "			[illegible]									
7 TH "			[illegible]									
[illegible]			[illegible]									
[illegible]			[illegible]									
10 TH "			[illegible]	1								
				1								
TOTALS	8	1	10	1								

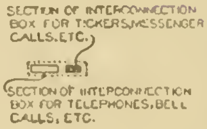

SECTION OF INTERCONNECTION BOX FOR TICKERS, MESSENGER CALLS, ETC.
SECTION OF INTERCONNECTION BOX FOR TELEPHONES, BELL CALLS, ETC.

Fig. 46. Wiring of an Office Building. Diagram of the Interconnection System.

basement; adjoining this main box is located the terminal box of the local telephone company. A separate system of feeders is provided for the ticker system, as these conductors require somewhat heavier insulation, and it was thought inadvisable to place them in the same conduits with the telephone wires, owing to the higher potential of ticker circuits. A separate interconnection cable runs to each floor, for telephone and messenger call purposes; and a central box is placed near the rising point at each floor, from which run subsidiary cables to several points symmetrically located on the various floors. From these subsidiary boxes, wires can be run to the various offices requiring telephone or other service. Small pipes are provided to serve as raceways from office to office, so as to avoid cutting partitions. In this way, wires can be quickly provided for any office in the building without damaging the building in any way whatever; and, as provision is made for a special wooden moulding near the ceiling to accommodate these wires, they can be run around the room without disfiguring the walls. All the main cables and subsidiary wires are connected with special interconnection blocks numbered serially; and a schedule is provided in the main interconnection box in the basement, which enables any wire originating thereat, to be readily and conveniently traced throughout the building. All the main cables and subsidiary cables are run in iron conduits.

OUTLET=BOXES, CUT=OUT PANELS, AND OTHER ACCESSORIES

Outlet-Boxes. Before the introduction of iron conduits, outlet-boxes were considered unnecessary, and with a few exceptions were not used, the conduits being brought to the outlet and cut off after the walls and ceilings were plastered. With the introduction of iron conduits, however, the necessity for outlet-boxes was realized; and the *Rules* of the Fire Underwriters were modified so as to require their use. The *Rules of the National Electric Code* now require outlet-boxes to be used with rigid iron and flexible steel conduits, and with armored cables. A portion of the rule requiring their use is as follows:

All interior conduits and armored cables "must be equipped at every outlet with an approved outlet-box or plate.

"Outlet-plates must not be used where it is practicable to install outlet-boxes.

"In buildings already constructed, where the conditions are such that neither outlet-box nor plate can be installed, these appliances may be omitted by special permission of the inspection department having jurisdiction, providing the conduit ends are bushed and secured."

Fig. 47 shows a typical form of outlet-box for bracket or ceiling outlets of the *universal type.* When it is desired to make an opening for the conduits, a blow from a hammer will remove any of the weakened portion of the wall of the outlet-box, as may be required. This form of outlet-box is frequently referred to as the *knock-out type.* Other forms of outlet-boxes are made with the openings cast in the box at the required points, this class being usually stronger and better made than the universal type. The advantages of the universal type of outlet-box are that one form of box will serve for any ordinary conditions, the openings being made according to the number of conduits and the directions in which they enter the box.

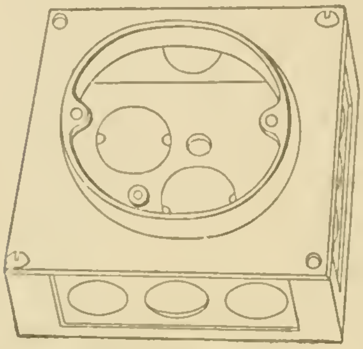


Fig. 47. Universal and Knock-Out Type of Outlet Box.

Fig. 48 shows a waterproof form of outlet-box used out of doors, or in other places where the conditions require the use of a watertight and waterproof outlet-box.

It will be seen in this case, that the box is threaded for the conduits, and that the cover is screwed on tightly and a flange provided for a rubber gasket.

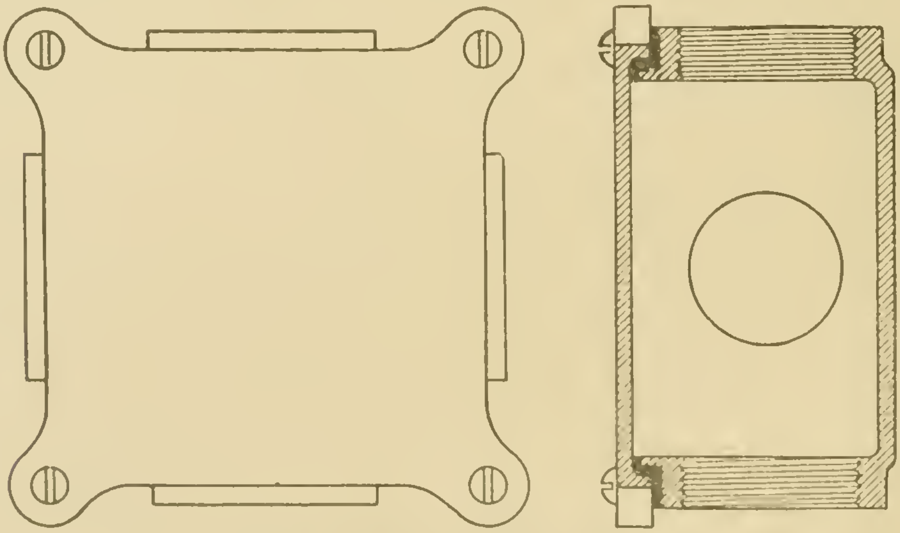


Fig. 48. Water-Tight Outlet Box.
Courtesy of H. Krantz Manufacturing Co., Brooklyn, N. Y.

Figs. 49 and 50 show water-tight floor boxes which are for outlets located in the floor. While the rules do not require that the floor outlet-box shall be water-tight, it is strongly recommended that a water-tight outlet be used in all cases for floor connections. In this case also, the conduit opening is threaded, as well as the stem cover through which the extension is made in the conduit to the desk or table. When the floor outlet connection is not required, the stem cover may be removed and a flat, blank cover be used to replace the same.

A form of outlet-box used for flexible steel cables and steel armored cable, has already been shown (see Fig. 5).

There is hardly any limit to the number and variety of makes of outlet-boxes on the market, adapted for ordinary and for special conditions; but the types illustrated in these pages are characteristic and typical forms.

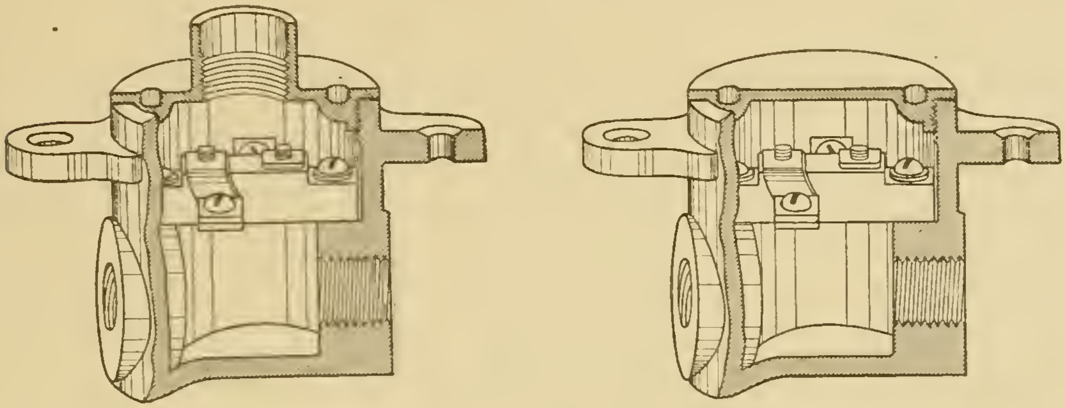


Fig. 49. Fig. 50.
Types of Floor Outlet-Boxes.

Bushings. The *Rules of the National Electric Code* require that conduits entering junction-boxes, outlet-boxes, or cut-out cabinets, shall be provided with approved *bushings*, fitted to protect the wire from abrasion.

Fig. 51 shows a typical form of conduit bushing. This bushing is screwed on the end of the conduit after the latter has been introduced into the outlet-box, cut-out cabinet, etc., thereby forming an insulated orifice to protect the wire at the point where it leaves the conduits, and to prevent abrasion, grounds, short circuits, etc. A lock-nut (Fig. 52) is screwed on the threaded end of the conduit before the conduit is placed in the outlet-box or cut-out cabinet, and this lock-nut and bushing clamp the conduit securely in position. Fig.

53 shows a terminal bushing for panel-boxes used for flexible steel conduit or armored cable.

The *Rules of the National Electric Code* require that the metal of conduits shall be permanently and effectually grounded, so as to insure a positive connection for grounds or leaking currents, and in order to provide a path of least resistance to prevent the current from finding a path through any source which might cause a fire. At outlet-boxes, the conduits and gaspipes must be fastened in such a manner as to insure good electrical connection; and at centers of distribution, the conduits should be joined by suitable bond wires, preferably of copper, the said bond wires being connected to the metal structure of the building, or, in case of a building not having an iron or steel structure, being grounded in a permanent manner to water or gas piping.

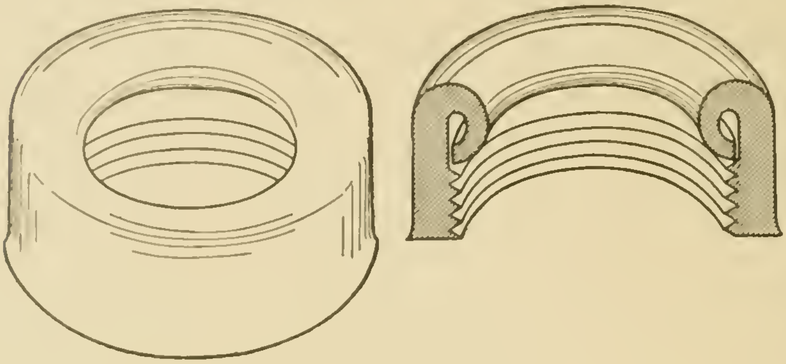


Fig. 51. Conduit Bushing.

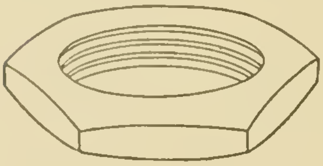


Fig. 52. Lock-Nut.

Fuse-Boxes, Cut-Out Panels, etc. From the very outset, the necessity was apparent of having a protective device in circuit with the conductor to protect it from overload, short circuits, etc. For this purpose, a fusible metal having a low melting point was employed. The form of this fuse has varied greatly. Fig. 54 shows a characteristic form of what is known as the *link fuse* with copper terminals, on which are stamped the capacity of the fuse.

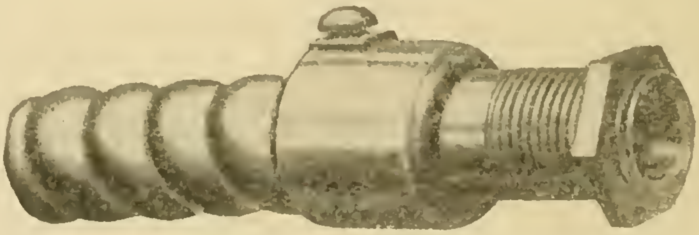
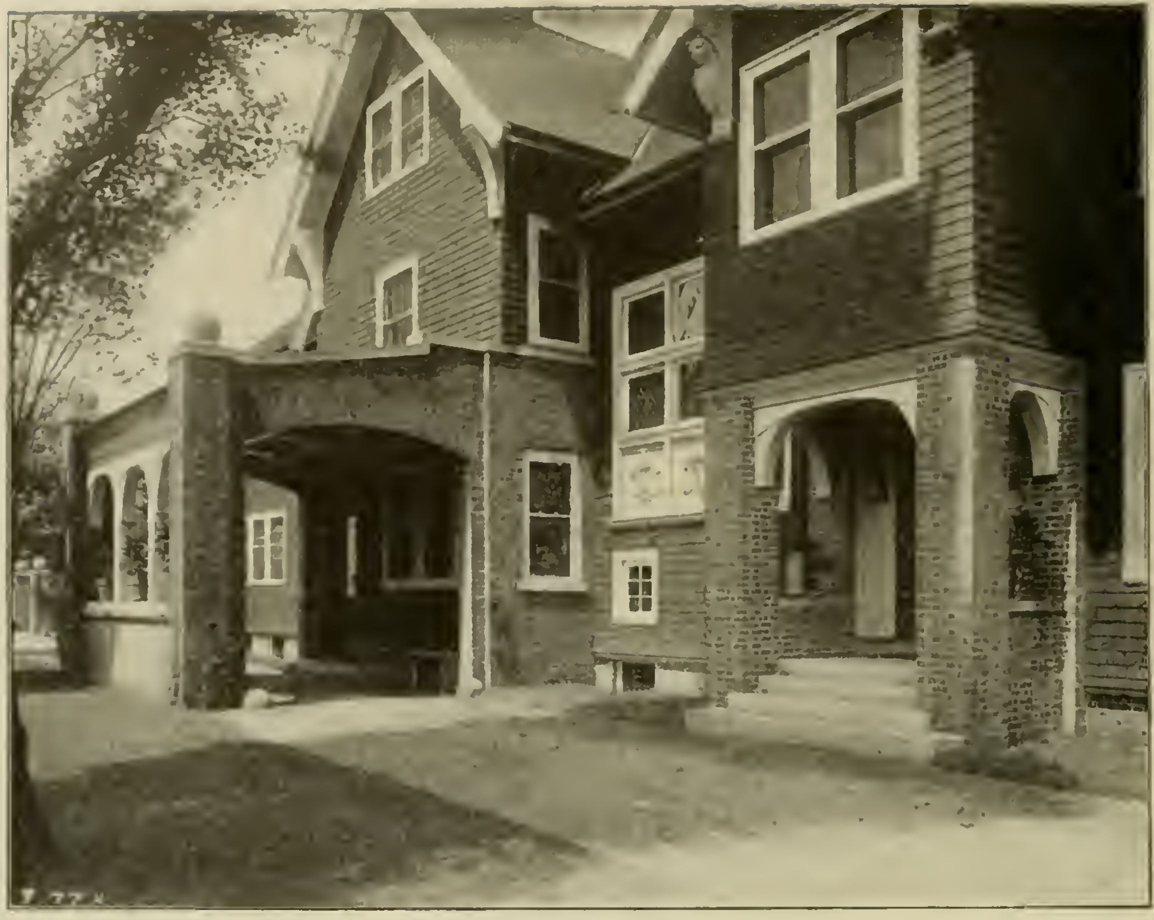
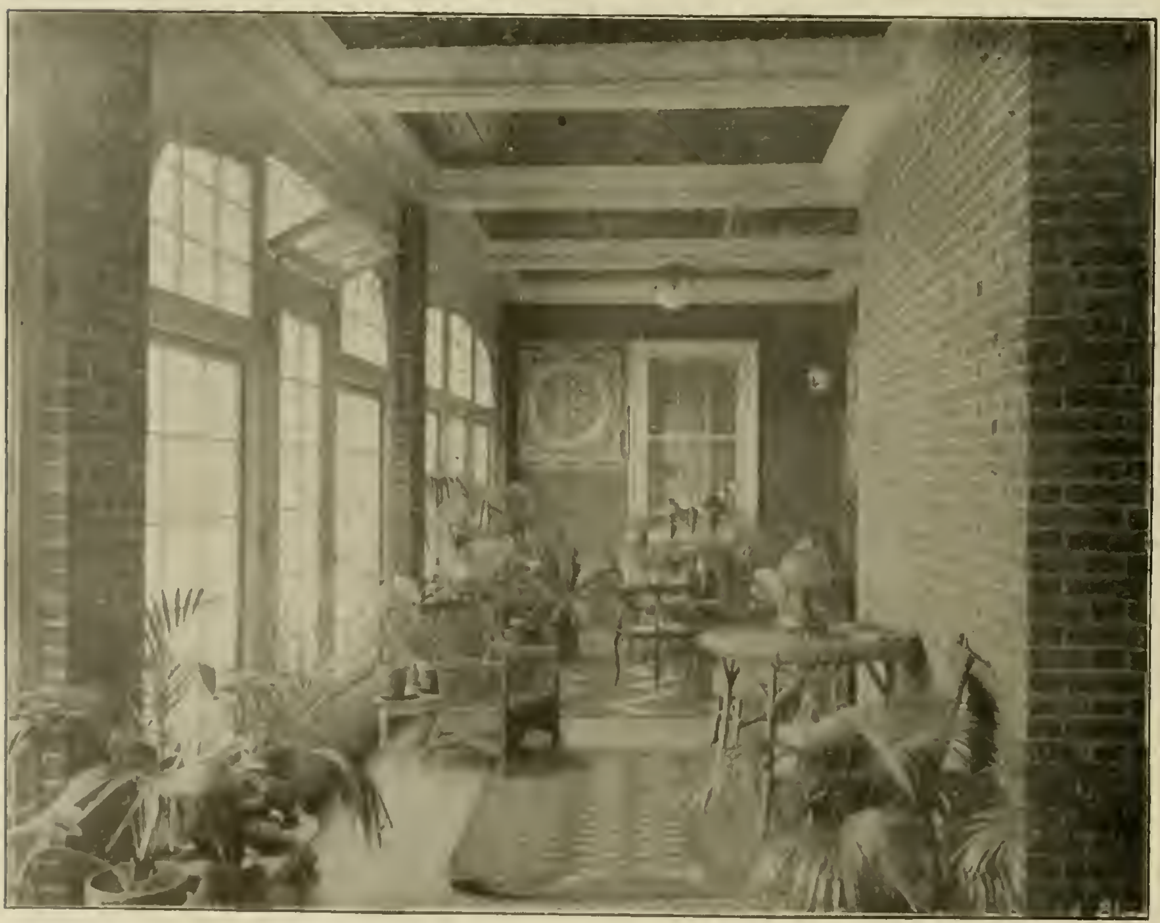


Fig. 53. Panel-Box Terminal Bushing.
Courtesy of Sprague Electric Co., New York, N. Y.

The form of fuse used probably to a greater extent than any other, although it is now being superseded by other more modern forms,



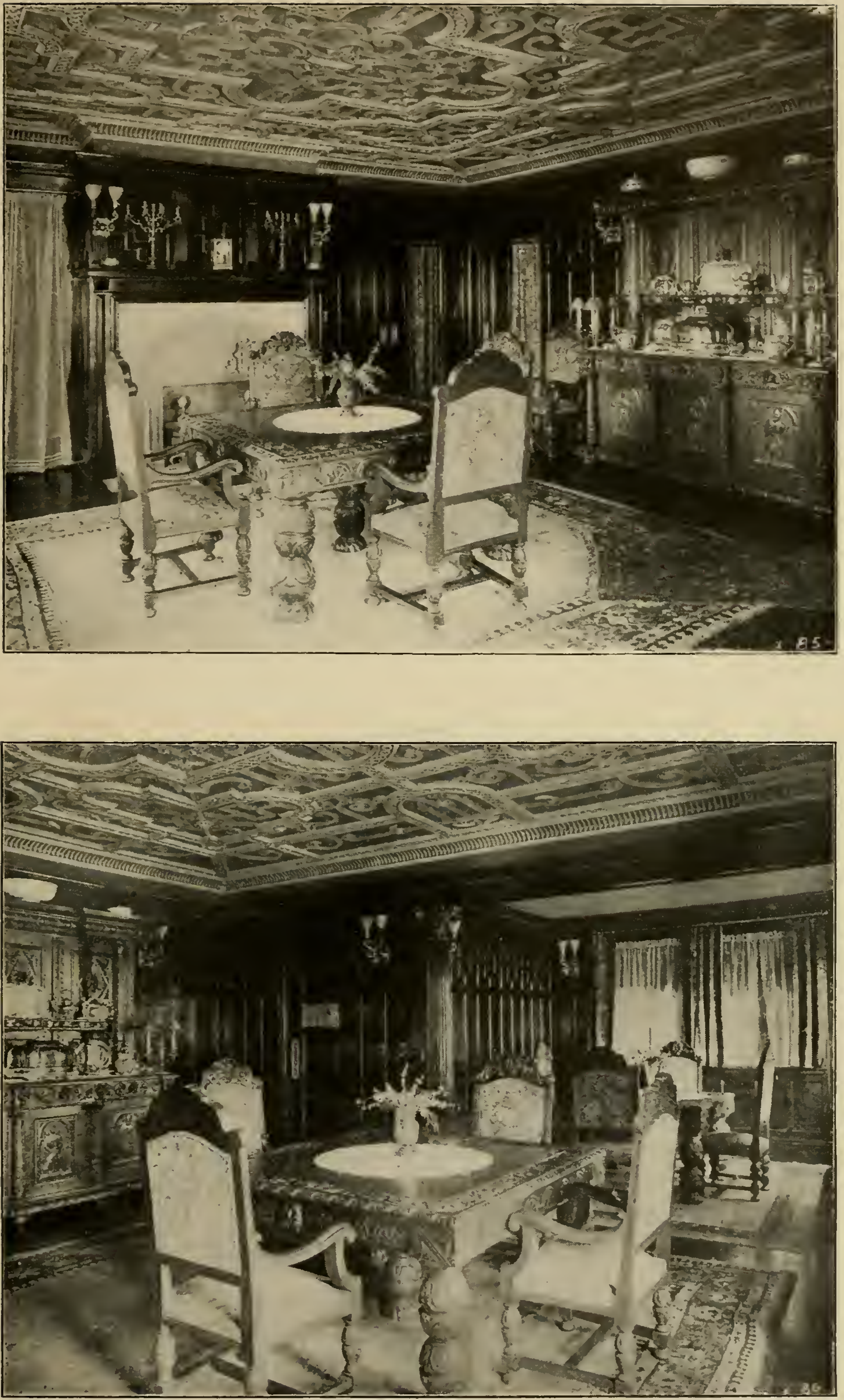
DETAIL OF RESIDENCE AT CLEVELAND, OHIO



ENCLOSED OPEN-AIR PORCH IN RESIDENCE AT CLEVELAND, OHIO

Frost & Granger, Architects, Chicago, Ill.

For Further Exteriors, See Vol. 1, Page 311; for Interior Views, See Opposite Page.



DINING ROOM IN RESIDENCE AT CLEVELAND, OHIO

Frost & Granger, Architects, Chicago, Ill.

Note the Absence of any Hanging Fixture. Other Details of Same House Shown on Opposite Page.

is that known as the *Edison fuse-plug,* shown in Fig. 55. A porcelain *cut-out block* used with the Edison fuse is shown in Fig. 56.

Within the last four or five years, a new form of fuse, known as the *enclosed fuse,* has been introduced and used to a considerable extent. A fuse of this type is shown in Fig. 57. Fig. 58 gives a sectional view of this fuse, showing the porous filling surrounding the fuse-strips, and also the device for indicating when the fuse has blown. This form of fuse is made with various kinds of terminals; it can be used with spring clips in small sizes, and with a post screw contact in larger sizes. For ordinary low potentials this fuse is desirable for currents up to 25 amperes; but it is a debatable question whether it is desirable to use an enclosed fuse for heavier currents. Fig. 59 shows a *cut-out box* with Edison plug fuse-blocks used with knob and tube wiring. It will be seen that there is no connection compartment in this fuse-box, as the circuits enter directly opposite the terminals with which they connect.

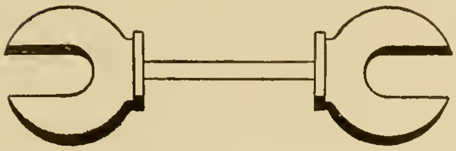


Fig. 54. Copper-Tipped Fuse Link.

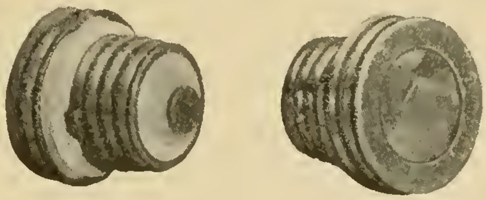


Fig. 55. Edison Fuse-Plug,
Courtesy of General Electric Co., Schenectady, N. Y.

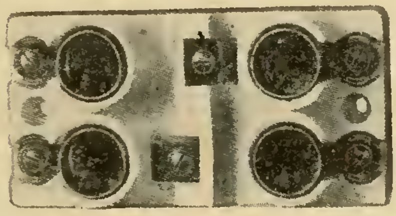


Fig. 56. Porcelain Cut-Out Block.
Courtesy of General Electric Co., Schenectady, N. Y.

Fig. 60 shows a *cut-out panel* adapted for enclosed fuses, and installed in a cabinet having a connection compartment. As will be seen from the cut, the tablet itself is surrounded on the four sides by slate, which is secured in the corners by angle-irons. The outer box may be of wood lined with sheet iron, or it may be of iron. Fig. 61 shows a door and trim for a cabinet of this type. It will be seen that

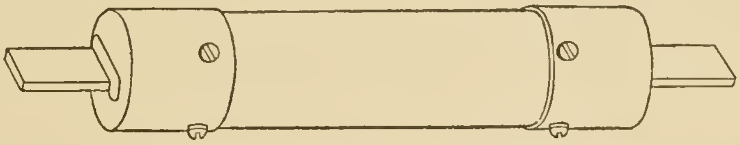


Fig. 57. Enclosed or "Cartridge" Fuse.

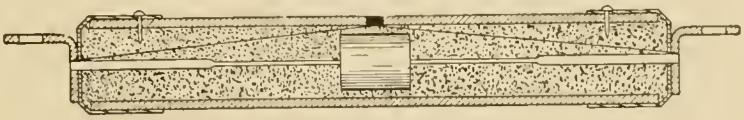


Fig. 58. Section of Enclosed Fuse.

the door opens only on the center panel, and that the trim covers and conceals the connection compartment. The inner side of the door should be lined with slate, and the inner side of the trim should be lined with sheet iron. Fig. 62 shows a sectional view of the cabinet and panel. In this type of cabinet, the conduits may enter at any point, the wires being run to the proper connectors in the connection compartment.

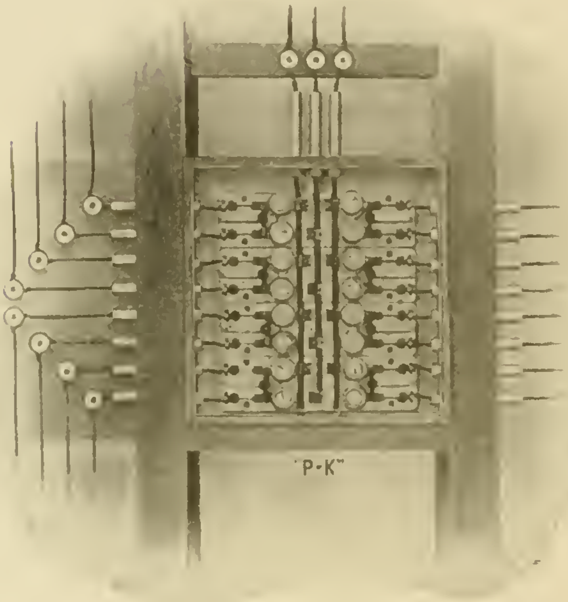


Fig. 59. Porcelain Cut-Outs in Wooden Box.
Courtesy of H. T. Paiste Co., Philadelphia, Pa.

Figs. 63 and 64 illustrate a type of panel-board and cabinet having a push-button switch connected with each branch circuit and so arranged that the cut-out panel itself may be enclosed by locked doors, and access to the switches may be obtained through two separate doors provided with latches only. This type of panel was arranged and designed by the author of this instruction paper.

OVERHEAD LINEWORK

The advantages of overhead linework as compared with underground linework are that it is much less expensive; it is more readily and more quickly installed; and it can be more readily inspected and repaired.

Its principal disadvantages are that it is not so permanent as underground linework; it is more easily deranged; and it is more unsightly.

For large cities, and in congested districts, overhead linework should not be used. However, the question of first cost, the question of permanence, and the municipal regulations, are usually the factors which determine whether overhead or underground linework shall be used.

The principal factors to be considered in overhead linework will be briefly outlined.

Placing of Poles. As a general rule, the poles should be set from 100 to 125 feet apart, which is equivalent to 53 to 42 poles per mile. Under certain conditions, these spacings given will have to be modified; but if the poles are spaced too far apart, there is danger of too great a strain on the poles themselves, and on the cross-arms, pins, and conductors. If, on the other hand, they are placed too close together, the cost is unnecessarily increased. The size and number of conductors, and the potential of the linework, determine to a great extent the distance between the poles; the smaller the size, the less the number of conductors; and the lower the potential, the greater the distance between the poles may be made. Of course, the exact location of the poles is subject to variation because of trees, buildings, or other obstructions. The usual method employed in locating poles, is first to make a map on a fairly large scale, showing the course of the linework, and then to locate the poles on the ground according to the actual conditions.

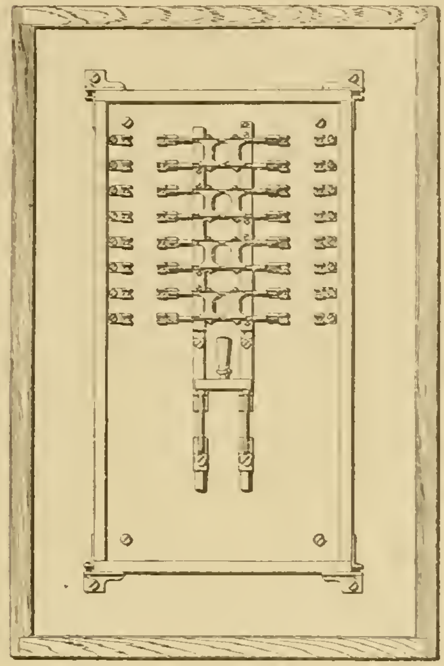


Fig. 60. Plan View, Cover, and Section of Double Cut-Out Box.

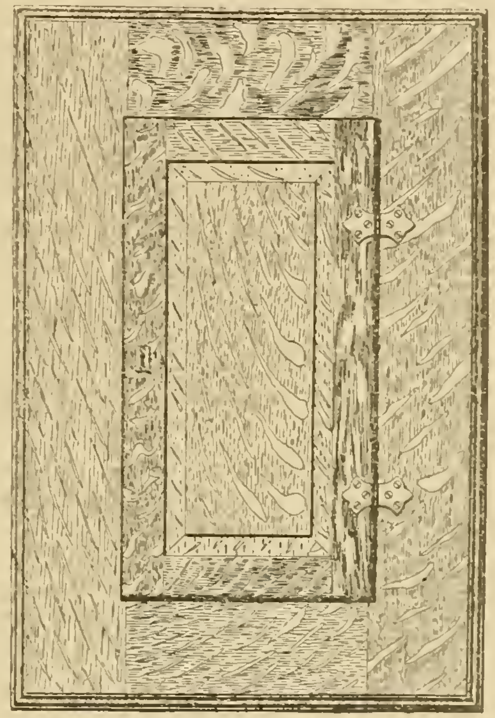


Fig. 61.

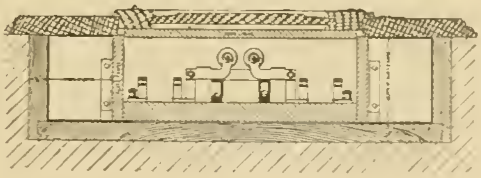


Fig. 62.

Poles. Poles should be of selected quality of chestnut or cedar, and should be sound and free from cracks, knots, or other flaws. Experience has proven that chestnut and cedar poles are the most durable and best fitted for linework. If neither chestnut nor cedar poles can be obtained, northern pine may be used, and even other timber in localities where these poles cannot be obtained; but it is found that the other woods do not last so long as those mentioned, and some of the other woods are not only less strong initially, but are apt to rot much quicker at the "wind and water line"—that is, just above and below the surface of the ground.

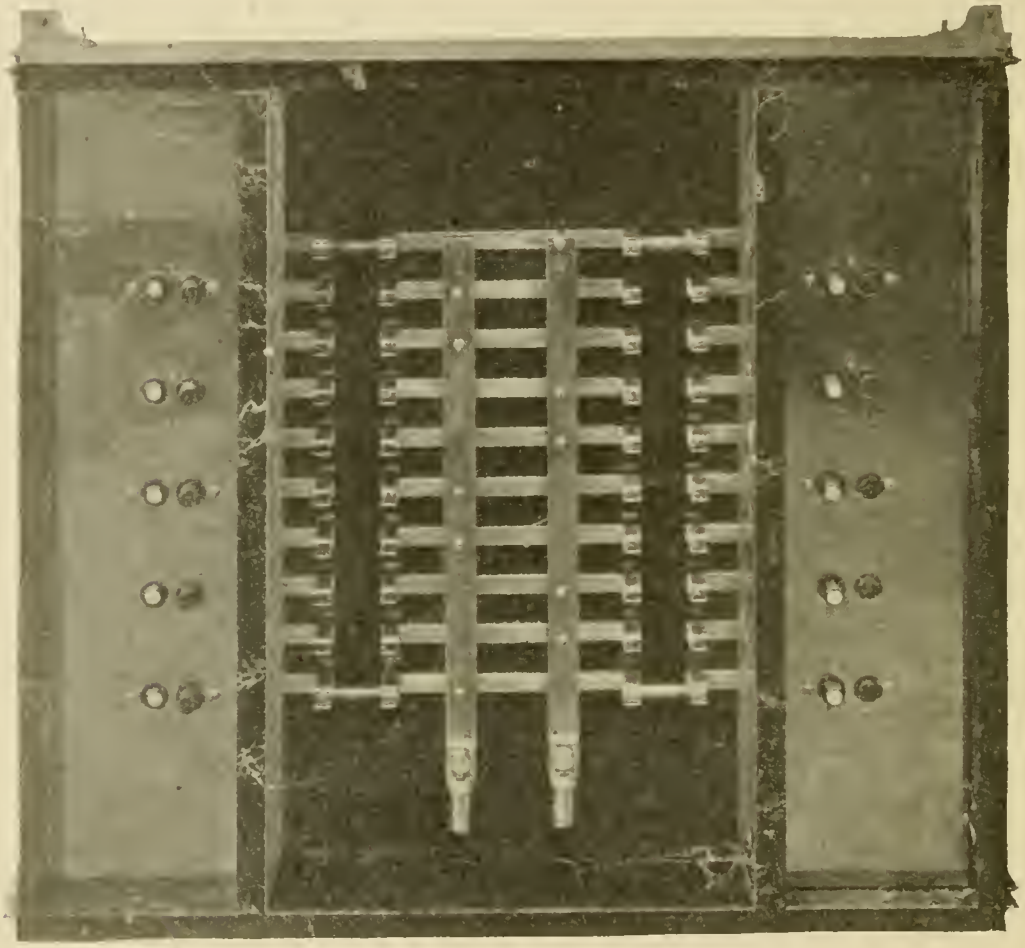


Fig. 63. Cut-Out Panel with Push-Button Switches. Cover Removed.

The proper height of pole to be used depends upon conditions. In country and suburban districts, a pole of 25 to 30 feet is usually of sufficient height, unless there are more than two or three cross-arms required. In more densely populated districts and in cities where a great number of cross-arms are required, the poles may have to be

40 to 60 feet, or even longer. Of course, the longer the pole, the greater the possibility of its breaking or bending; and as the length increases, the diameter of the butt end of pole should also increase. Table X gives the average diameters required for various heights of poles, and the depth the poles should be placed in the ground. These data have been compiled from a number of standard specifications.

TABLE X

Pole Data

Length of Pole	Diameter 6 In. from Butt	Diameter at Top	Depth Pole should be Placed in Ground
25 feet	9 to 10 in.	6 to 8 in.	5 feet
30 "	11 "	"	5½ "
35 "	12 "	"	5½ "
40 "	13 "	"	6 "
45 "	14 "	"	6½ "
50 "	15 "	"	7 "
55 "	16 to 17 "	"	7½ "
60 "	18 "	"	7½ "
65 "	19 "	"	8 "
70 "	20 "	"	8 "
75 "	21 "	"	8½ "
80 "	22 "	"	9 "

As it is somewhat difficult, because of irregularities in size, to measure the diameter of some poles, the circumference may be measured instead; then, by multiplying the diameters given in the above table, by 3.1416, the measurements may be reduced to the circumference in inches.

The minimum diameters of the pole at the top, which should be allowed, will depend largely on the size of the conductors used, and on the potential carried by the circuits; the larger the conductors and the higher the potentials, the greater should be the diameter at the top of the pole.

Poles should be shaved, housed, and gained, also cleaned and ready for painting, before erection.

Poles should usually be painted, not only for the sake of appearance, but also in order to preserve them from the weather. It is particularly important that they should be protected at their butt end, not only where they are surrounded by the ground, but for a foot or two above the ground, as it is at this point that poles usually deteriorate most rapidly. Painting is not so satisfactory at this point as the use of tar, pitch, or creosote. The life of the pole can be increased considerably by treating it with one or another of these preservatives.

Before any poles are erected, they should be closely inspected for flaws and for crookedness or too great departure from a straight line.

Where appearance is of considerable importance, octagonal poles may be used, although these cost considerably more than round poles. *Gains* or notches for the cross-arms should be cut in the poles before they are erected, and should be cut square with the axis of the pole, and so that the cross-arms will fit snugly and tightly within the space thus provided. These gains should be not less than 4½ inches wide, nor less than ½ inch deep. Gains should not be placed closer than 24 inches between centers, and the top gains should be at least 9 inches from the apex of the pole.

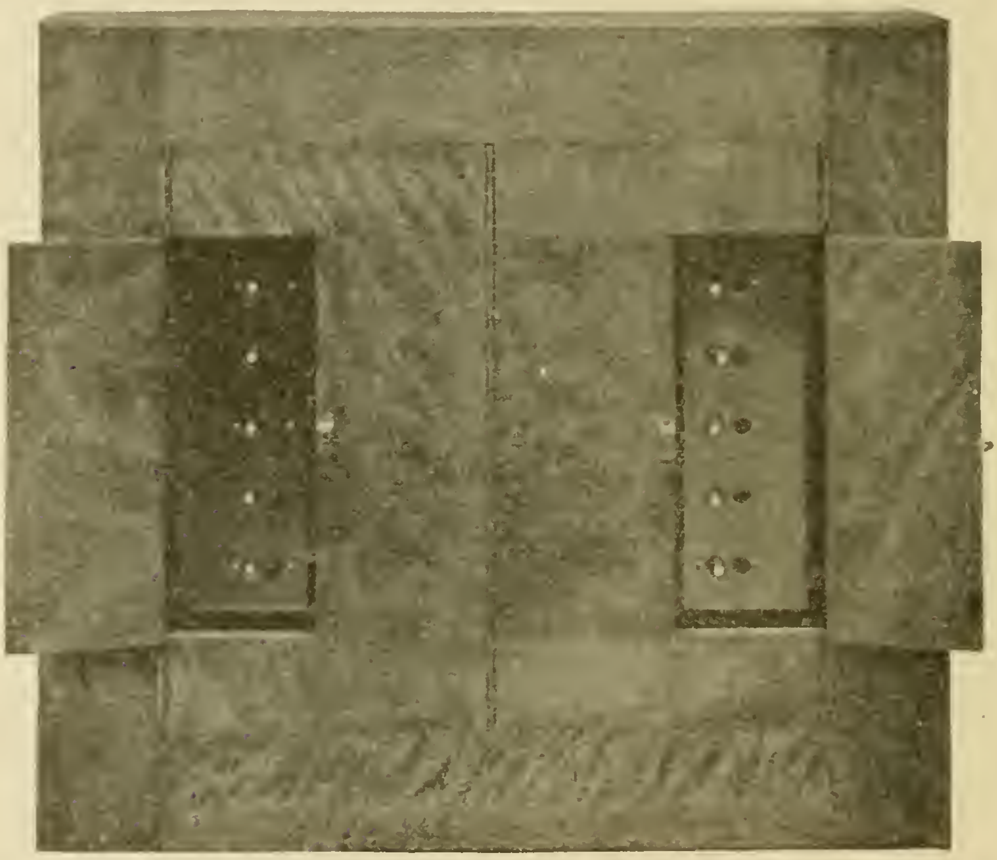


Fig. 61. Cut-Out Panel with Push-Button Switches. With Cover.

ELECTRIC BELL WIRING.

In wiring for electric bells to be operated by batteries, the danger of causing fires from short circuits or poor contacts does not exist as in the case of wiring for light and power, because the current strength is so small. Neither is the bell-fitter responsible to city inspectors or fire underwriters. On this account, bell fitting is too often done in a careless and slovenly manner, causing the apparatus to give unsatisfactory results and to require frequent repairs, so that the expense and inconvenience in the end far more than offset any time saved by doing an inferior grade of work. Hence, at the outset it is well to state that as much care should be taken in the matter of joints and insulation of bell wiring as in wiring for light or power.

If properly installed, the electric bell forms a reliable and yet inexpensive means of signaling, and is far superior to any other. On this account practically every new building is fitted throughout with electric bells.

In addition to the necessity of thoroughness already mentioned, care should be taken to use only reliable apparatus which must be installed in accordance with the fundamental principles on which its satisfactory operation depends.

WIRE.

The common sizes of wire in use for bell work are Nos. 18, 20, and 22. In general, however, No. 20 will be found satisfactory as it is usually sufficiently large, while in many cases No. 22 is not strong enough from a mechanical standpoint.

It is important that the wires should be well insulated to prevent accidental contacts with the staples or other wires. First of all the wire should be tinned, as this prevents the copper from being acted upon by the sulphur in the insulation. It also facilitates soldering. The inner coating of insulation should be of

Fig. 1.

india rubber, surrounded by several longitudinal strands of cotton, outside of which are wound several strands of colored cotton laid on spirally. This is next immersed in melted paraffin wax and polished by friction. A short length of approved electric bell wire is shown in Fig. 1.

When ordering wire, it is well to have it furnished in several different colors as this greatly facilitates both the original installation and later repairs, because in this way one line may be distinguished from another, taps from main lines, etc. Moreover, a faulty wire having been found, it is possible to identify it at any desired section of its length.

METHODS OF WIRING.

In running wires, the shortest and most direct route should, of course, be taken between the battery, bells, and bell pushes. There are two cases to be considered. The better method is that in which the wires are run before the building is completed, and the wiring should be done as soon as the roof is on and the walls are up. In this case the wires are usually run in zinc tubes secured to the walls with nails. The tubes should be from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch in diameter, preferably the latter. It is better to place the wires and tubes simultaneously, but the tubes may be put in place first and the wires drawn in afterward, although this latter plan has the objection that the insulation is liable to become abraded when the wires are drawn in. In joining up two lengths of tube, the end of one piece should be opened up with the pliers so that it may receive the end of the other tube, which should also be opened up, but to a less extent, to prevent wear upon the insulation. Specially prepared paper tubes are sometimes substituted for the zinc.

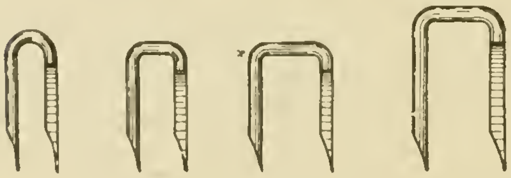


Fig. 2.

If the building is completed before the wiring is done, the concealed method described above cannot be used, and it is necessary to run the wires along the walls supported by staples, where they will be least conspicuous. Fig. 2 shows ordinary double-pointed tacks, Fig. 3 shows an insulating saddle staple which is to be recommended. Two wires should never be secured under the same staple if it can possibly be avoided, owing to the danger of short circuits. With a little care it is usually possible to conceal the wiring behind the picture moulding, along the skirting-board, and beside the door posts, but where it is impossible to conceal it, a light ornamental casing to match the finish of the room, may be used. It is sometimes advisable to use twin wires or two insulated wires run in the same outer covering.

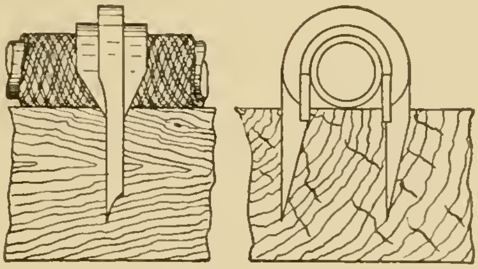


Fig. 3.

In some cases it is well to run the wires under the floors, laying them in notches in the tops of the joists or in holes bored about two inches below the tops of the joists.

JOINTS.

When making a joint, care should be taken to have a firm, clean connection, both mechanically and electrically, and this must always be soldered to prevent corrosion. The insulation should be stripped off the ends of the wires to be joined, for a distance of about 2 inches, and the wires made bright by scraping or sandpapering. They should then be twisted tightly and evenly together as shown in Fig. 4.

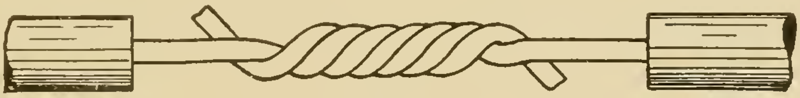


Fig. 4.

Next comes the operation of **soldering,** which is absolutely necessary if a permanent joint from an electrical standpoint is to be obtained. A joint made without solder may be electrically sound at first, but its resistance rapidly increases, due to deterioration of the joint. As has already been stated, the wires should be made bright and clean before they are twisted together. Soldering fluids should never be used, because they cause corrosion of the wire. The best flux to use is resin or composite candle. The soldering should always be done with a copper bit rather than with a blowpipe or wireman's torch.

A convenient form of soldering tool consists of a small copper bit having a semicircular notch near the end. This bit should, of course, be well tinned. It is then heated over a spirit lamp, or wireman's torch, and the notch filled with soft solder. Lay the joint, which has previously been treated with the flux, in this notch and turn it so that the solder runs completely around among the spirals of the joint. The loose solder should be shaken off or removed with a bit of rag. When the joint is set, it should be insulated with rubber tape, so that it will be protected as perfectly as the other portions.

It is often possible to save a considerable length of wire and amount of labor by using a ground return, which, if properly arranged, will give very satisfactory results, although a complete metallic circuit is always to be preferred. Where water or gas mains are available, a good ground may be obtained by connecting to them, being sure to have a good connection. This may be secured by scraping a portion of the pipe perfectly bright and clean and then winding this with bare wire; the whole is then well soldered. An end should be left to which the wire from the bell circuit is twisted and soldered. If such mains are not available, a good ground can be obtained by connecting the wire from the bell circuit, as described above, to a pump pipe. In the absence of water and gas mains, and of a pump pipe, a ground may be obtained by burying beneath permanent moisture level a sheet of copper or lead, having at least five square feet of surface, to which the return wire is connected. The ground plate should be covered with coke nearly to the surface; the hole should then be filled in with ordinary soil well rammed.

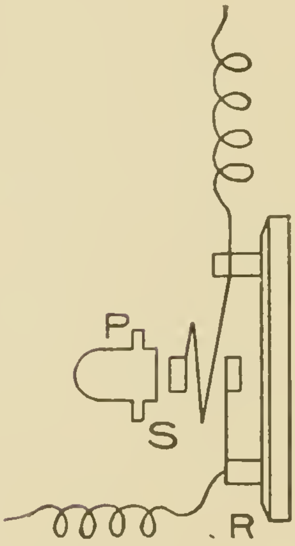


Fig. 5.

OUTFIT.

The three essential parts of the electric bell outfit are the bell push, which furnishes a means of opening and closing the circuit at will, the battery, which furnishes the current for operating the bell, and the bell itself. Before discussing the combination of these pieces of apparatus in the complete circuit, let us take up the individual parts in order.

A bell push is shown diagrammatically in Fig. 5. In this illustration P is the push button; when this is pressed upon it brings the point of the spring S in contact with the metal strip R, thus closing the circuit with which it is connected in series. Normally the springs are separated as shown, and the circuit is accordingly open.

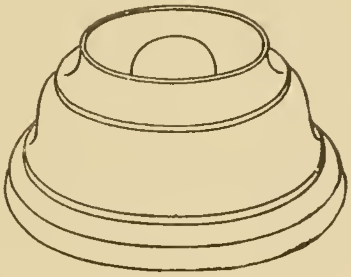


Fig. 6.

Bell pushes are made in various designs and styles, from the simple wooden push shown in Fig. 6 to very elaborate and expensive articles. Fig. 7 shows four cast bronze pushes of neat appearance and moderate price.

Batteries. Electric bells are nearly always operated on the open circuit plan, and hence the battery used is generally of the open circuit type, such as the Leclanche cell, which is used very largely except for heavy work. This is a zinc-carbon cell in which the excitant is sal-ammoniac dissolved in water. Polarization is prevented by peroxide of manganese, which gives up part of its oxygen, combining with the hydrogen set free and forming water.

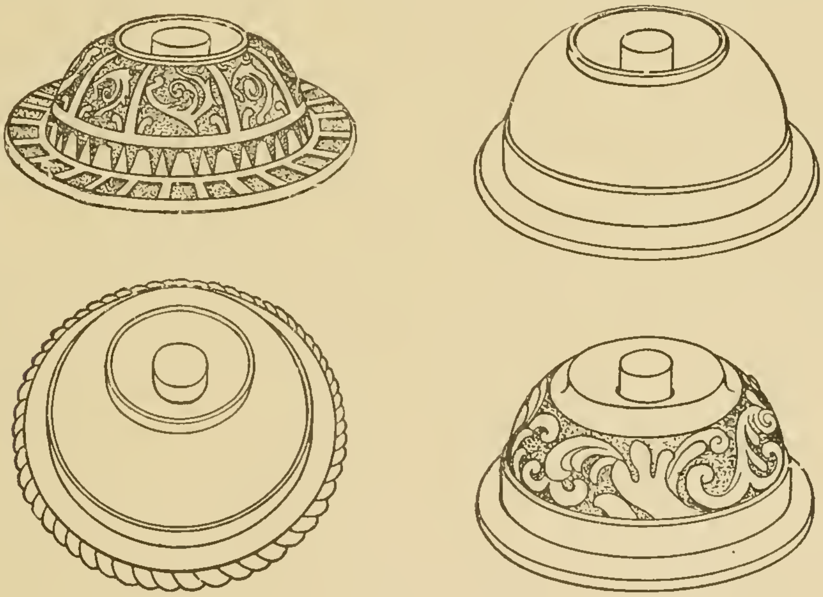


Fig. 7.

Dry Batteries are also frequently used for bell work, their principal advantage being cleanliness, as they cannot spill. Dry cells are really a modification of the Leclanche type, as they use zinc and carbon plates and sal-ammoniac as the exciting agent. The Burnley cell, which is one of the principal types of dry cell, has an electrolyte composed of sal-ammoniac, chloride of zinc, plaster, flour, and water. This compound when mixed is a semi-liquid mass which quickly stiffens after being poured into the cup. The depolarizing agent is peroxide of manganese, the same as is used in the Leclanche cell, this being packed around the carbon cylinder. The top of the cell is sealed with bitumen or some similar substance.

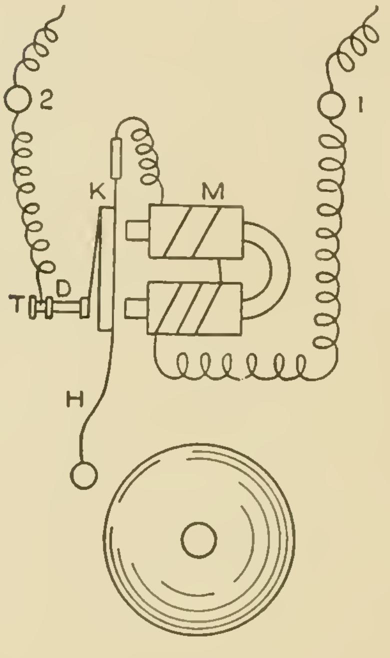


Fig. 8.

For very heavy work the Edison-Lalande and the Fuller types of cell are best suited, while for closed circuit work the gravity cell is most satisfactory.

Bell. It is a well-known fact that if a current of electricity flows through a coil of wire wound on an iron core, the core becomes magnetized and is capable of attracting any magnetic substances to itself. The operation of the electric bell, like that of so many other pieces of electrical apparatus, depends upon this fact. A diagrammatic representation of an electric bell is shown in Fig. 8, in which M is an electromagnet composed of soft-iron cores on which are wound coils of insulated wire. The armature is mounted upon a spring K, and carries a hammer H at its end for striking the gong. On the back of the armature is a spring which makes contact at D with the back stop T. The action of the bell is as follows: When the circuit is closed through the bell a current flows from terminal 1, around the coils of the magnet, through the spring K and contact point D, through the back stop T, to terminal 2. In flowing around the electromagnet the current magnetizes its core, which consequently attracts the armature. This causes the hammer H to strike the gong. While in this position the contact at D is broken, the current ceases to flow around the electromagnet and the cores consequently lose their attractive force. The armature is then carried back to its original position by the spring K, making contact at D, and the process is repeated. The hammer will thus vibrate and the bell continue to ring as long as the circuit is closed.

The type of bell described above is the one most commonly used. Such bells are made in a great variety of shapes and styles, the prices varying accordingly. It is important that platinum tips be furnished at the contact point D, Fig. 8, to prevent corrosion. The bells on the market today are of two classes, the iron box bell and the wooden box bell. A bell of the wooden box type is shown in Fig. 9, and a higher grade bell of the iron frame skeleton type is shown in Fig. 10. Bells without covers should never be used, as dust will settle on the contacts and interfere with their action.

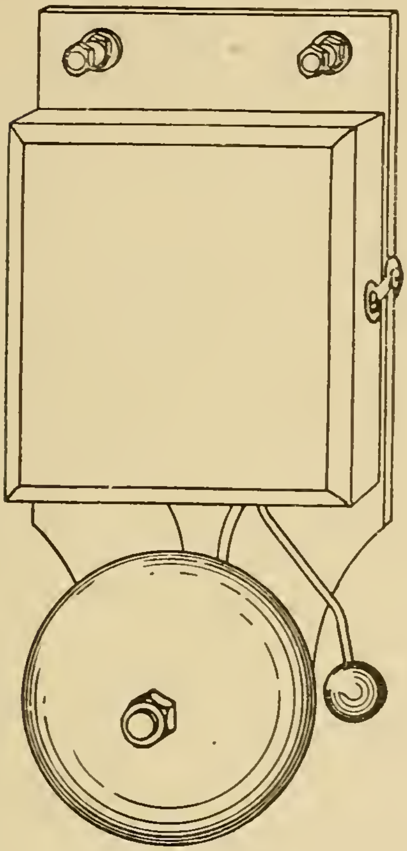


Fig. 9.

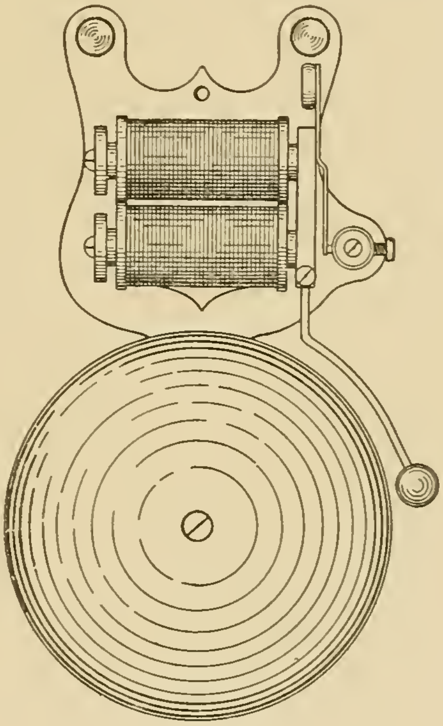


Fig. 10.

CIRCUITS.

The possible combinations of the various parts into complete circuits are so varied that it would be impossible to describe them all; in fact, almost every one is to a certain extent a special problem. It is, however, possible to give typical circuits the underlying principles of which can be applied successfully to any particular case.

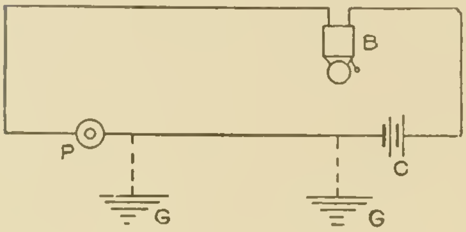


Fig. 11.

Fig. 11 shows a bell circuit in its simplest form, in which P represents the push, B the bell, and C the battery; all connected in series. The circuit is normally open at P, and hence no current flows to exhaust the batteries. When P is pressed, the circuit, otherwise complete, is closed and current passes through the bell causing it to ring, as already explained. For instance, the push might be located beside the front door, the bell in the kitchen and the battery in the cellar; the location depending on the results desired and conditions to be met. The wire between P and C may, if necessary, be dispensed with and connection made to ground at G and G, as shown by the dotted lines.

Fig. 12 shows an arrangement by means of which one bell B may be controlled by either of the pushes P or P'. This system may be extended to any number of pushes similarly connected.

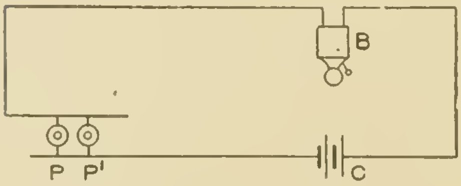


Fig. 12.

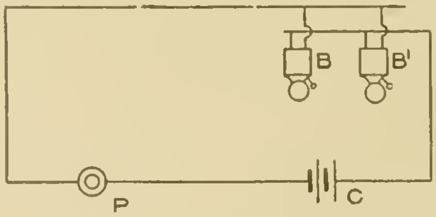


Fig. 13.

A method for ringing two bells simultaneously from one push is shown in Fig. 13, where both bells B and B' will ring from push P. Bells, if connected in this manner, should have as nearly as possible the same resistance, otherwise the bell of lower resistance will take so much current that there will not be a sufficient amount left for the other. Also, the batteries must be of greater current capacity as the amount of current taken is, of course, doubled. This system can be extended to any number of bells connected in this way, up to the limit of capacity of the battery to ring them. Figs.

12 and 13 may be combined so that two or more bells may be rung from any one of two or more pushes.

In Fig. 14 is shown a scheme for ringing either bell, B or B′, from one push and one battery by means of the two-point switch S. When the arm of the switch is on contact 1, the push will ring bell B, and when on contact 2 it will ring bell B′.

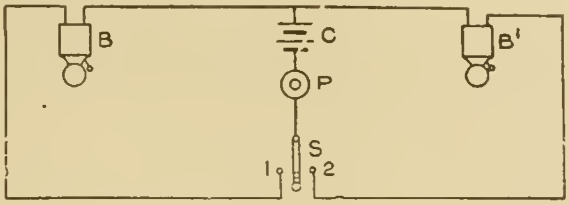


Fig. 14.

In Fig. 15 is shown a method of connecting bells in series so that B and B′ may be rung from P. If all the bells so connected were of the vibrating type, they would not work satisfactorily, as it would be impossible to time them so that the vibrations would keep step, hence only one bell should be of the vibrating type, and the others should have the circuit breakers short-circuited, the vibrating bell serving as interrupter for the whole series. Obviously this system requires a higher voltage than parallel connection, and the cells must be of sufficient E.M.F. to ring the bells satisfactorily. Several bells may be connected in this way, if desired, up to the limit of voltage of the battery.

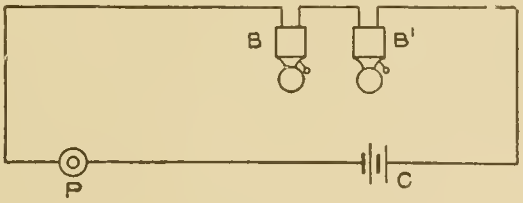


Fig. 15.

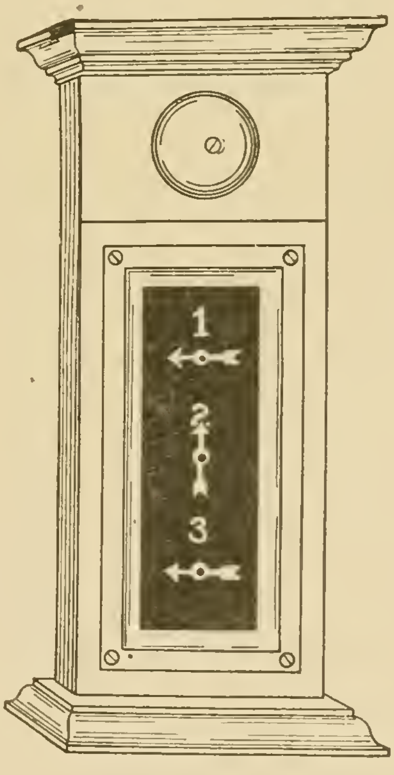


Fig. 16.

Oftentimes a bell is to be rung from several different places. For instance, the bell in an elevator may be rung from any one of several floors, or the bell in the office of a hotel may be rung from any one of several different rooms. In this case it is necessary to have some device to indicate from which push the bell was rung. The annunciator furnishes this information very well. A three-station annunciator is shown in Fig. 16. The connections for an annunciator are shown in Fig. 17 where A represents the annunciator, B the bell, C the battery, and P^1, P^2, and P^3 the pushes. For instance, when P^1 is pressed, the current passes through the electromagnet controlling point 1 on the annunciator which causes the arrow to be turned and at the same time the bell rings. After the attendant has noted the signal, the arrow is restored to its normal position by pressing a lever on the bottom of the annunciator box.

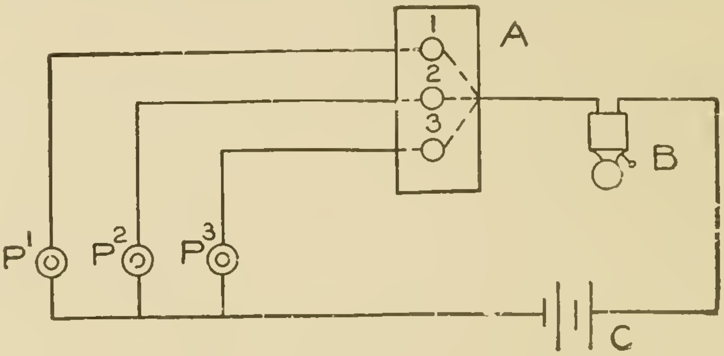
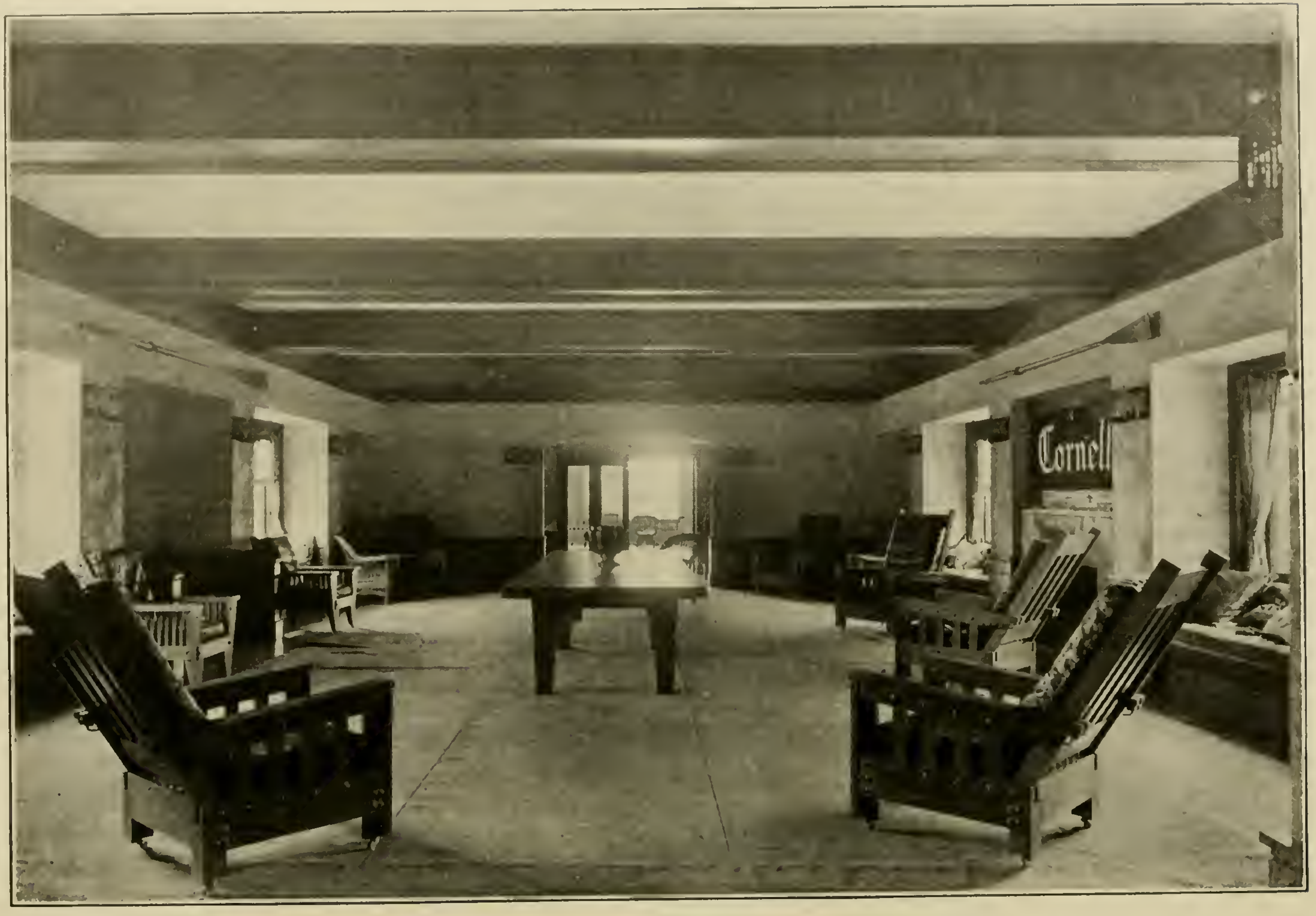


Fig. 17.

The electric burglar alarm furnishes a very efficient protection and is an application of the principles already described. The circuit, instead of being completed by a push, is completed by contacts placed on the doors or windows so that the opening of either will cause the bell to ring. The same device may be used on money-drawers, safes, etc.

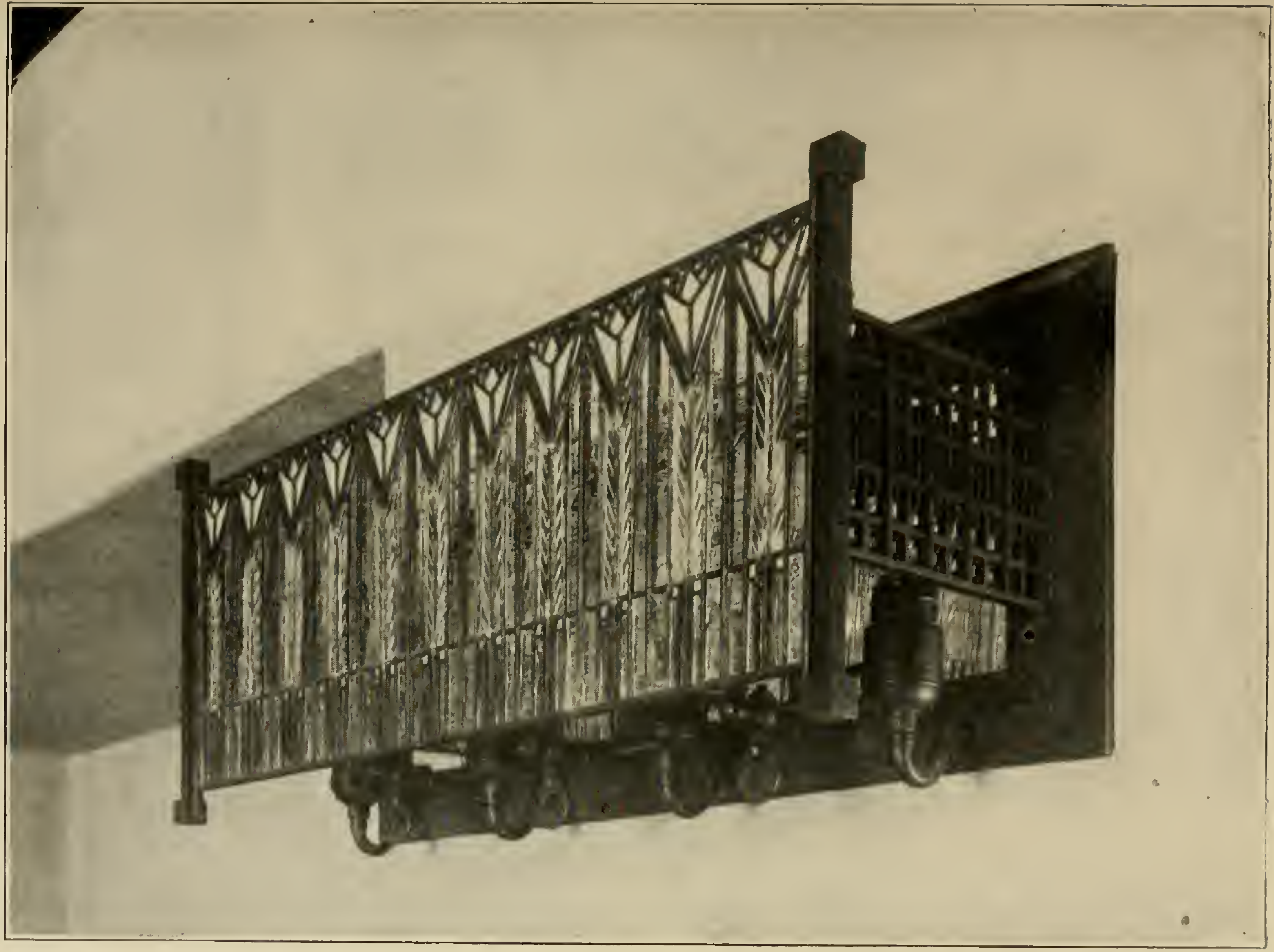
In the case of the electric fire alarm, the signal may be given either automatically when the temperature reaches a certain degree, or pushes may be placed in convenient locations to be operated manually. The pushes should be protected by glass so that they will not be tampered with, it being necessary to break the glass to give the alarm.



LIVING ROOM IN ALPHA DELTA PHI CHAPTER-HOUSE AT CORNELL UNIVERSITY, ITHACA, N. Y.

Dean & Dean, Architects, Chicago, Ill.

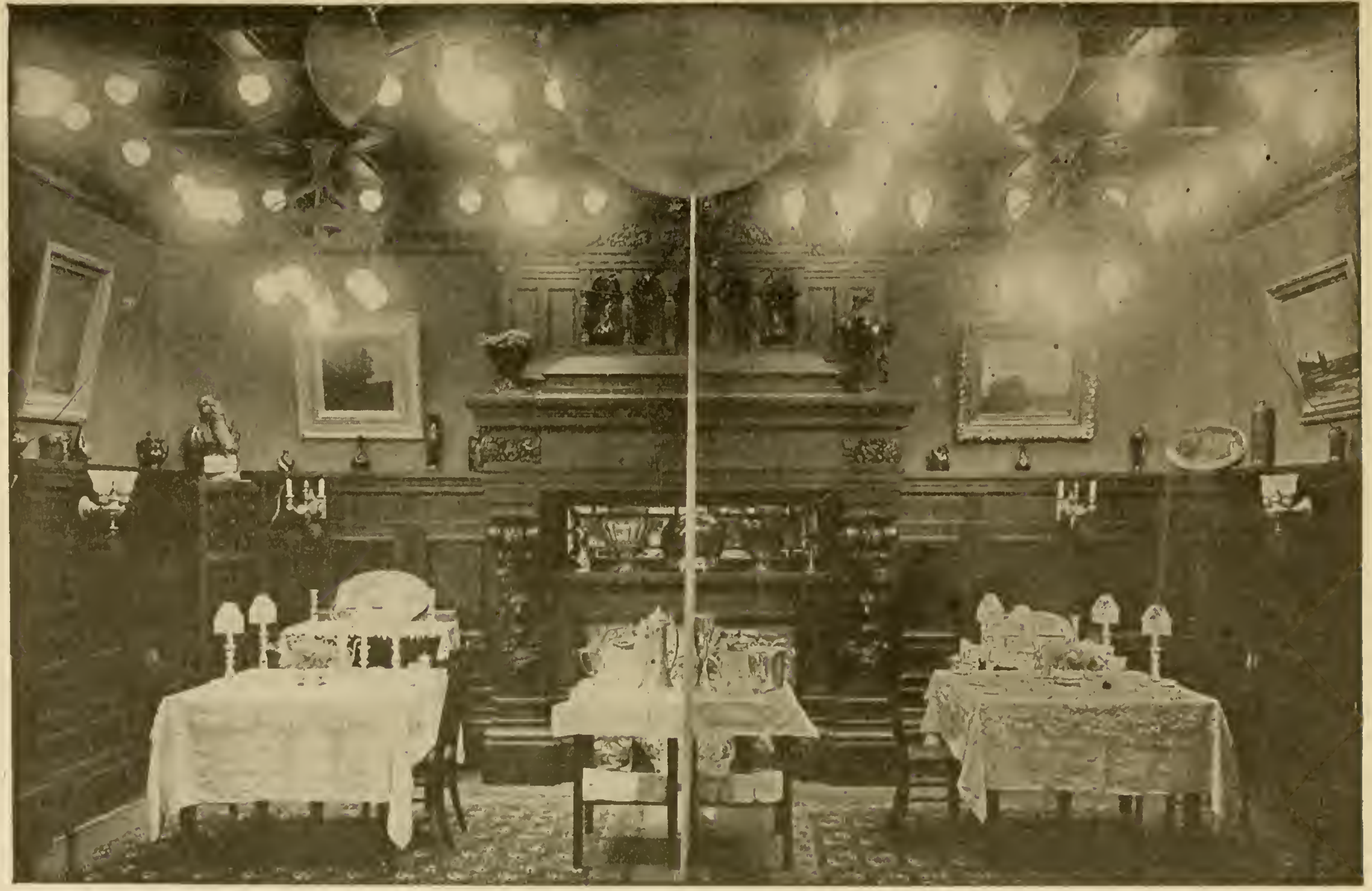
Oak Stained a Gray Green and Waxed; Furniture to Match; Plaster Stained and Waxed. For Plans and Exterior, See Vol. III, Pages 282 and 298; for other Interiors, see Page 298 in this Volume.



GAS AND ELECTRIC FIXTURE IN LIVING ROOM OF ALPHA DELTA PHI CHAPTER-HOUSE AT CORNELL UNIVERSITY, ITHACA, N. Y.

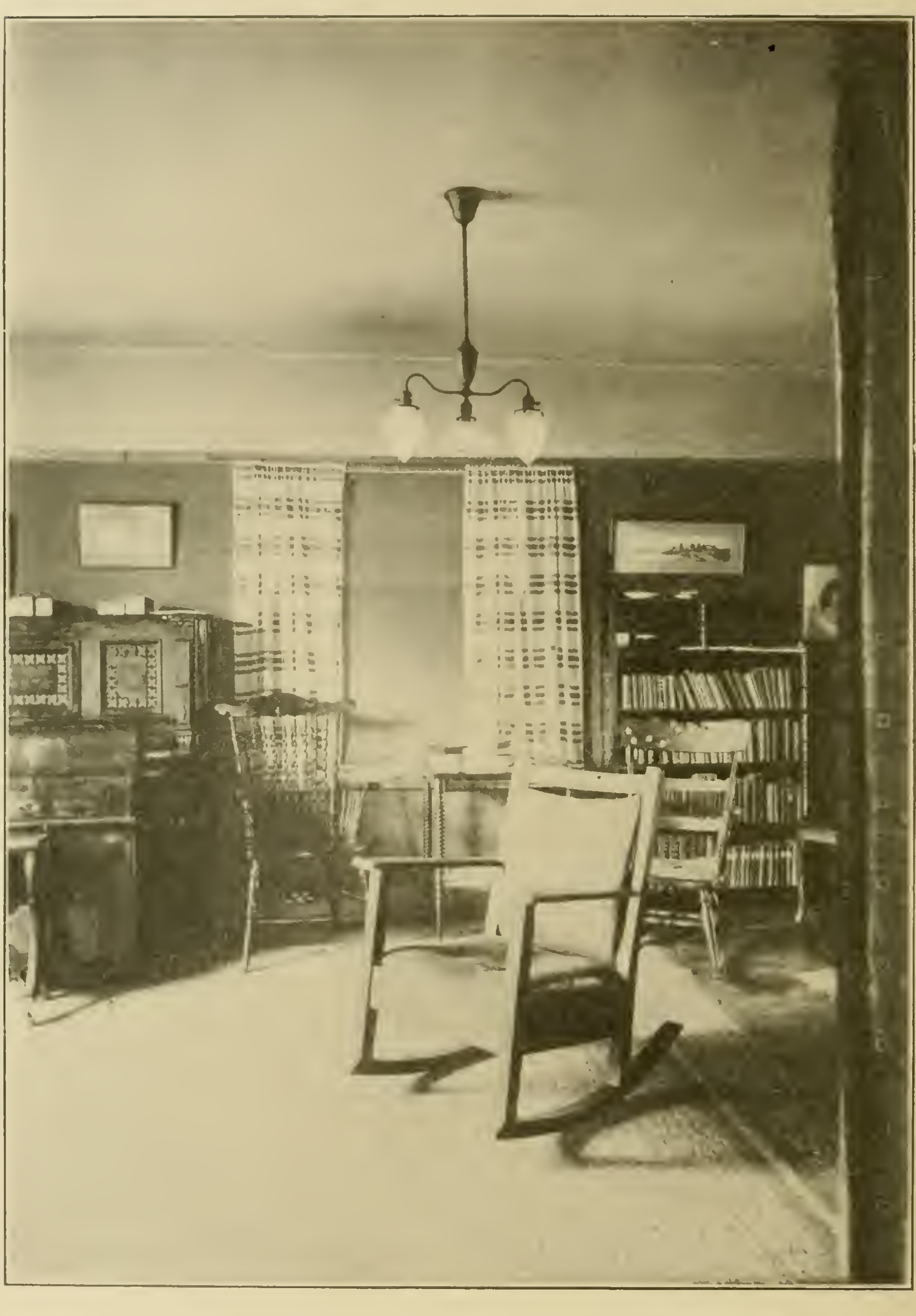
Dean & Dean, Architects, Chicago, Ill.

Corrugated Mirror in the Iron Frame; Iron Brackets and Leaded Glass Screen.



HOLOPHANE EXHIBIT.

World's Fair, St. Louis.



LIVING ROOM IN RESIDENCE OF J. R. CRAVATH, CHICAGO, ILL.
A good Arrangement for Reading and General Lighting in a Small Room.

ELECTRIC LIGHTING.

HISTORY AND DEVELOPMENT.

The history of electric lighting as a commercial proposition begins with the invention of the Gramme dynamo (by Z. J. Gramme) in 1870, together with the introduction of the Jablochkoff candle or light, which was first announced to the public in 1876, and which formed a feature of the International Exposition at Paris in 1878. Up to this time, the electric light was known to but few investigators, one of the earliest being Sir Humphrey Davy who, in 1810, produced the first arc of any great magnitude. It was then called the "voltaic arc", and resulted from the use of two wood charcoal pencils as electrodes and a powerful battery of voltaic cells as a source of current.

From 1840 to 1859, many patents were taken out on arc lamps, most of them operated by clockwork, but these were not successful, due chiefly to the lack of a suitable source of current, since all depended on primary cells for their power. The interest in this form of light died down about 1859, and nothing further was attempted until the advent of the Gramme dynamo.

The incandescent lamp was but a piece of laboratory apparatus up to 1878, at which time Edison produced a lamp using a platinum spiral in a vacuum, as a source of light, the platinum being rendered incandescent by the passage of an electric current through it. The first successful carbon filament was made in 1879, this filament being formed from strips of bamboo. The names of Edison and Swan are intimately connected with these early experiments.

From this time on, the development of electric lighting has been very rapid, and the consumption of incandescent lamps alone has reached several millions each year. When we compare the small amount of lighting done by means of electricity twenty-five years ago with the enormous extent of lighting systems and the numerous applications of electric illumination as they are today, the growth and development of the art is seen to be very great, and the value of a study of this subject may be readily appreciated. While in many cases electricity is not the cheapest source of power for illumination, its admirable qualities and convenience of operation make it by far the most desirable.

Classification. The subject of Electric Lighting may be classified as follows:

1. The type of lamps used.
2. The methods of distributing power to the lamps.
3. The use made of the light, or its application.
4. Photometry and lamp testing.

Taking up these branches in the order named, we may further subdivide the types of lamps used into:

1. Incandescent lamps.
2. Arc lamps.
3. Special lamps, or lamps which do not require carbon, such as the Nernst lamp, Cooper-Hewitt lamp, etc.

The Incandescent Lamp. The incandescent lamp is by far the most common type of lamp used, and the principle of its operation is as follows:

If a current I is sent through a conductor whose resistance is R, for a time t, the conductor is heated, and the amount of heat generated is:

Heat generated $= I^2R\,t$, $I^2R\,t$ representing joules or watt-seconds.

If the current, material, and conditions are so chosen that the substance may be heated in this way until it gives out light, becomes incandescent, and does not deteriorate too rapidly, we have an incandescent lamp. Carbon is the substance chosen for this conductor and for ordinary lamps it is formed into a small thread or filament. Carbon is selected for two reasons:

1. The material must be capable of standing a very high temperature, 1280 to 1330° C.

2. It must be a conductor of electricity with a fairly high resistance.

Platinum has been used for the material, but, as we shall see, its temperature cannot be maintained at a value high enough to make the lamp as efficient as when carbon is used. Nearly all attempts to substitute another substance in place of carbon have failed, and the few lamps which are partially successful will be treated under the head of special lamps. The nature of the carbon employed in incandescent lamps has, however, been much improved over the first forms, and the method of manufacture will be treated next.

MANUFACTURE OF INCANDESCENT LAMPS.

Preparation of the Filament. Cellulose, a chemical compound rich in carbon, is prepared by treating absorbent cotton with zinc chloride in proper proportions to form a uniform, gelatine-like mass. It is customary to stir this under a partial vacuum in order to remove bubbles of air which might be contained in it and destroy its uniformity. This material is then forced, "squirted," through steel dies into alcohol, the alcohol serving to harden the soft, transparent threads. These threads are then thoroughly washed to remove all trace of the zinc chloride, dried, cut to the desired lengths, wound on forms, and carbonized by heating to a high temperature away from air. During carbonization, the cellulose is transformed into pure carbon, the volatile matter being driven off by the high temperature to which the filaments are subjected. The material becomes hard and stiff, assuming a permanent form, shrinking in both length and diameter; the form being specially constructed so as to allow for this shrinkage. The forms are made of carbon blocks which are placed in plumbago crucibles and packed with powdered carbon; the crucibles are covered with loosely fitting carbon covers. The crucibles are gradually brought to a white heat, at which temperature the cellulose is changed to carbon, and then allowed to cool. After cooling, the filaments are removed, measured and inspected, and the few defective ones discarded.

In the early days, these filaments were made of cardboard or bamboo, and later of thread treated with sulphuric acid.

A few of the shapes of filaments now in use are shown in Fig. 1, the different shapes giving a slightly different distribution of light. The shapes here shown are designated as follows: A, U-shaped; B, single-curl; C, single-curl anchored; D, double-loop; E, double-curl; F, double-curl anchored.

Mounting the Filament. After carbonization, the filaments are mounted or joined to wires leading into the globe or bulb. These wires are made of platinum—platinum being the only substance, so far as known, that expands and contracts the same as glass with change in temperature and which, at the same time, will not be melted by the heat developed in the carbon. Since the bulb must remain air-tight, a substance expanding at a different rate from the glass cannot be used. Several methods of fastening the filament to the "leading in" wires have been used, such as forming a socket in the end of the wire, inserting the filament and then squeezing the socket tightly against the carbon, and the use of tiny bolts when cardboard filaments were used, but the pasted joint is now used almost exclusively. Finely powdered carbon is mixed with some adhesive compound, such as molasses, and this mixture is used as a paste for fastening the carbon to the platinum. Later, when current is sent through the joint, the volatile matter is driven off and only the carbon remains. This makes a cheap and, at the same time, a very efficient joint.

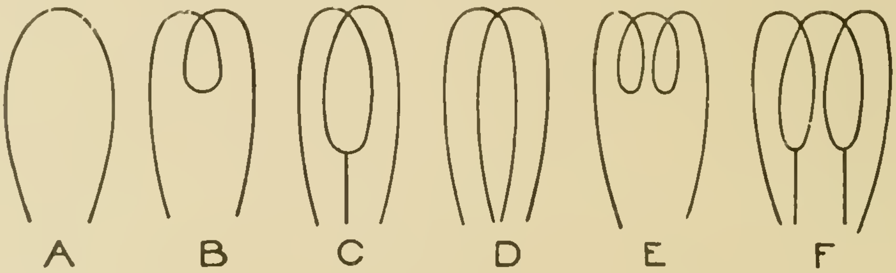


Fig. 1.

Flashing. Filaments, prepared and mounted in the manner just described, are fairly uniform in resistance, but it has been found that their quality may be much improved and their resistance very closely regulated by depositing a layer of carbon on the outside of the filament by the process of "flashing". By flashing is meant heating the filament to a high temperature when immersed in a hydrocarbon gas, such as gasoline vapor, under partial vacuum. Current is passed through the filament in this process to accomplish the heating. Gas is used, rather than a liquid, to prevent too heavy a deposit of the carbon. Coal gas is not recommended because the carbon, when deposited from this, has a dull black appearance. The effects of flashing are as follows:

1. The diameter of the filament is increased by the deposited carbon and hence its resistance is decreased. The process must be discontinued when the desired resistance is reached. Any little irregularities in the filament will be eliminated since the smaller sections, having the greater resistance, will become hotter than the remainder of the filament and the carbon is deposited more rapidly at these points.

2. The character of the surface is changed from a dull black and comparatively soft nature to a bright gray coating which is much harder and which increases the life and efficiency of the filament.

Exhausting. After flashing, the filament is sealed in the bulb and the air exhausted through the tube A in Fig. 2, which shows the lamp in different stages of its manufacture. The exhaustion is accomplished by means of mechanical air pumps, supplemented by Sprengle or mercury pumps and chemicals. Since the degree of exhaustion must be high, the bulb should be heated during the process so as to drive off any gas which may cling to the glass. When chemicals are used, as is now almost universally the case, the chemical is placed in the tube A and, when heated, serves to take up much of the remaining gas. Exhaustion is necessary for several reasons :

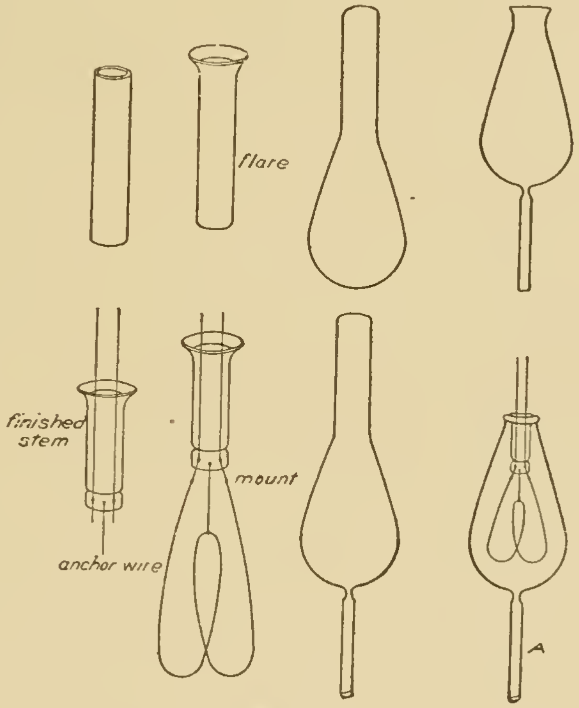


Fig. 2.

1. To avoid oxidization of the filament.
2. To reduce the heat conveyed to the globe.
3. To prevent wear on the filament due to currents or eddies in the gas.

After exhausting, the tube A is sealed off and the lamp completed for testing by attaching the base by means of plaster of Paris. Fig. 3 shows some of the forms of completed incandescent lamps.

Voltage and Candle-Power. Incandescent lamps vary in size from the miniature battery and candelabra lamps to those of several hundred candle-power, though the latter are very seldom used. The more common values for the candle power are 8, 16, 25, 32, and 50, the choice of candle-power depending on the use to be made of the lamp.

The voltage will vary depending on the method of distribution of the power. For what is known as parallel distribution, 110 or 220 volts are generally used. For the higher values of the voltage, long and slender filaments must be used, if the candle-power is to be low, and lamps of less than 16 candle-power for 220-volt circuits are not practical, owing to difficulty in manufacture. For series distribution, a low voltage and higher current is used, hence the filaments may be quite heavy. Battery lamps operate on from 4 to 24 volts, but the vast majority of lamps for general illumination are operated at or about 110 volts.

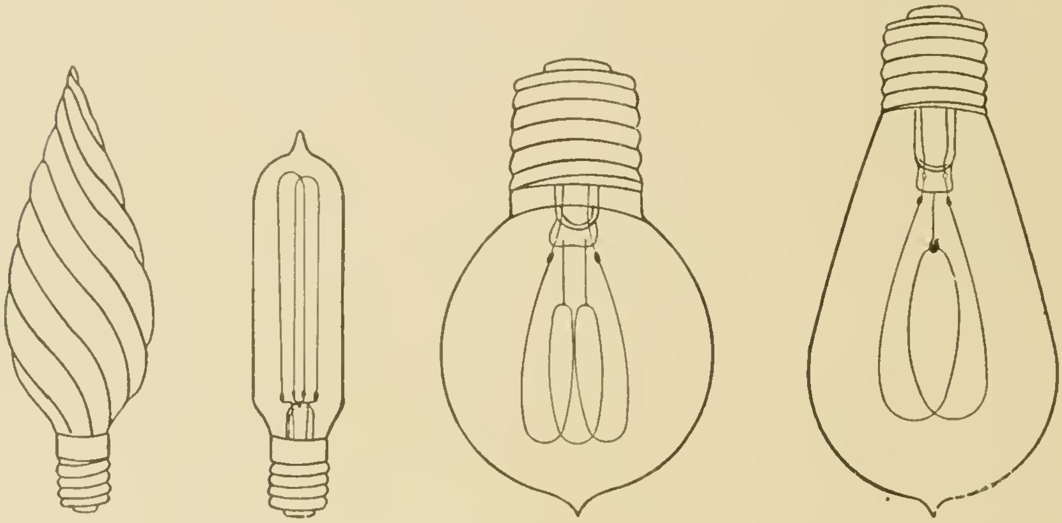


Fig. 3.

Efficiency. By the efficiency of an incandescent lamp is meant the power required at the lamp terminals per candle-power of light given. Thus, if a lamp giving an average horizontal candle-power of 16 consumes $\frac{1}{2}$ an ampere at 112 volts,-the total number of watts consumed will be $112 \times \frac{1}{2} = 56$, and the watts per candle-power will be $56 \div 16 = 3.5$. The efficiency of such a lamp is said to be 3.5 watts per candle-power. "Watts economy" is sometimes used for "efficiency".

The efficiency of a lamp depends on the temperature at which the filament is run. This temperature is between 1280° and 1330° C, and the curve in Fig. 4 shows the increase of efficiency with the increase of temperature. The temperature attained by a filament depends on the rate at which heat is radiated and the amount of power supplied. The rate of radiation of heat is proportional to the area of the filament, the elevation in temperature, and the emissivity of the surface.

By emissivity is meant the number of heat units emitted from unit surface per degree rise in temperature above that of surrounding bodies. The bright surface of a flashed filament has a lower emissivity than the dull surface of an unheated filament, hence less energy is lost in heat radiation and the efficiency of the filament is increased.

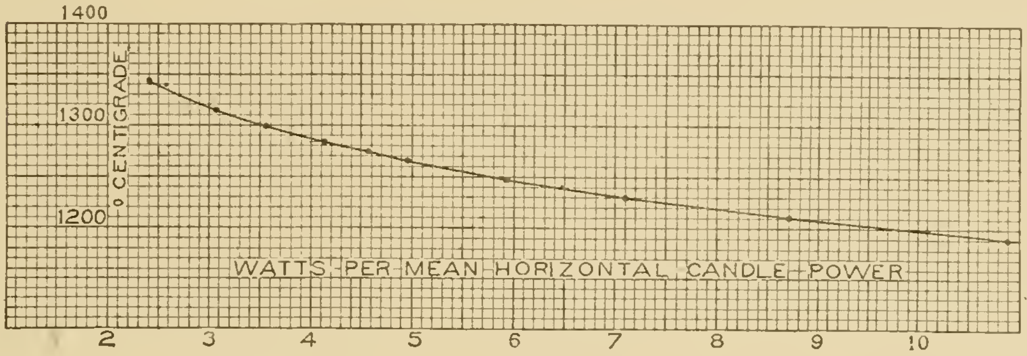


Fig. 4.

As soon as incandescence is reached, the illumination increases much more rapidly than the emission of heat, hence the increase in efficiency shown in Fig. 4. Were it not for the rapid disintegration of the carbon at high temperature, an efficiency higher than 3.1 watts could be obtained.

Relation of Life to Efficiency. By the useful life of a lamp is meant the length of time a lamp will burn before its candle-power has decreased to such a value that it would be more economical to replace the lamp with a new one than to continue to use it at its decreased value. A decrease to 80% of the initial candle-power is now taken as the point at which a lamp should be replaced, and the normal life of a lamp is in the neighborhood of 800 hours. To obtain the most economical results, lamps should always be replaced at the end of their useful life.

In Table 1 are given values of the efficiency and life of a 3.5-watt, 110-volt lamp for various voltages impressed on the lamp. These values are plotted in Fig. 5. These curves show that a 3% increase of voltage on the lamp reduces the life by one-half, while an increase of 6% causes the useful life to fall to one-third its normal value. The effect is even greater when 3.1-watt lamps are used, but not so great with 4-watt lamps. From this we see that the regulation of the voltage used on the system must be very good if high efficiency lamps are to be used, and this regulation will determine the type of lamp to be installed.

Selection of Lamps. Lamps taking 3.1 watts per candle-power will give satisfaction only when the regulation of voltage is the best—practically a constant voltage maintained at the normal voltage of the lamp.

TABLE I.

Effects of Change in Voltage.

Standard 3.5 Watt Lamp.

Voltage Per Cent. of Normal.	Candle-Power Per Cent. of Normal.	Watts Per Candle-Power.	Life Per Cent. of Normal.	Deterioration Per Cent. of Normal.
90	53	5.36		
91	56	5.09		
92	61	4.85		
93	65	4.63	-	
94	69	4.44	394	25
95	73	4.26	310	32
96	78	4.09	247	44
97	83	3.93	195	51
98	88	3.78	153	65
99	94	3.64	126	79
100	100	3.5	100	100
101	106	3.38	84	118
102	111	3.27	68	146
103	116	3.16	58	173
104	123	3.05	47	211
105	129	2.95	39	253
106	137	2.85	31	316
107	143	2.76	26	380
108	152	2.68	21	474
109	159	2.60	17	575
110	167	2.53	16	637

Lamps of 3.5 watts per candle-power should be used when the regulation is fair, say with a maximum variation of 2% from the normal voltage.

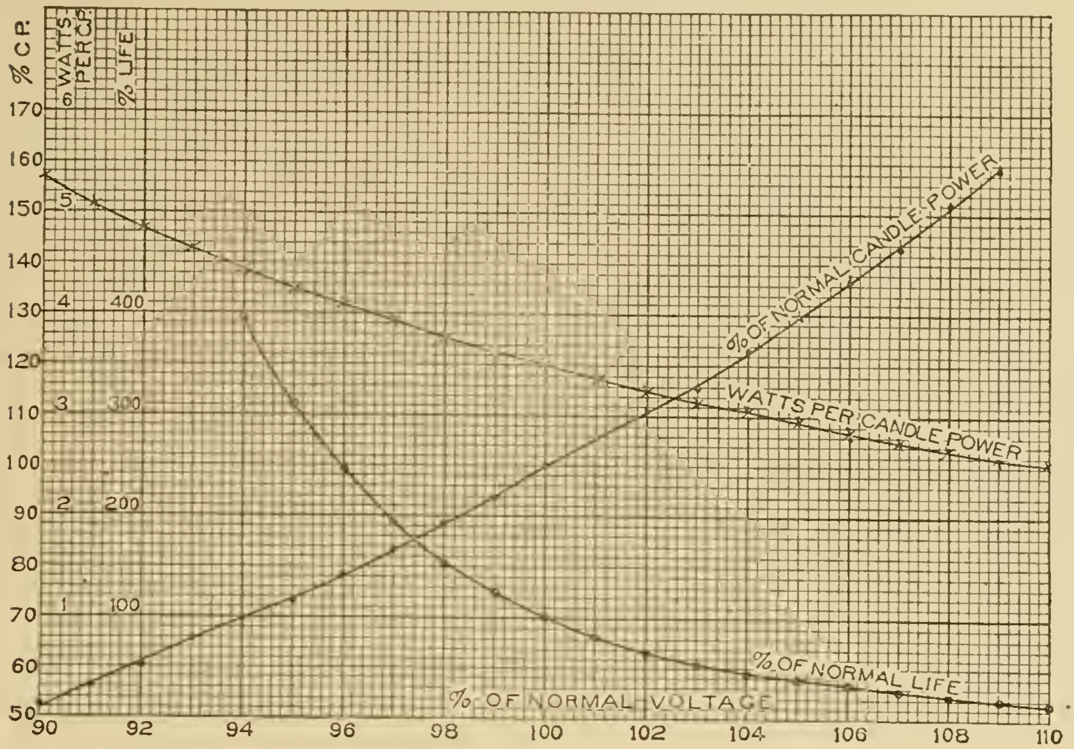


Fig. 5.

Lamps of 4 watts per candle-power should be installed when the regulation is poor. These values are for 110-volt lamps. A 220-volt lamp should have a lower efficiency to give a long life.

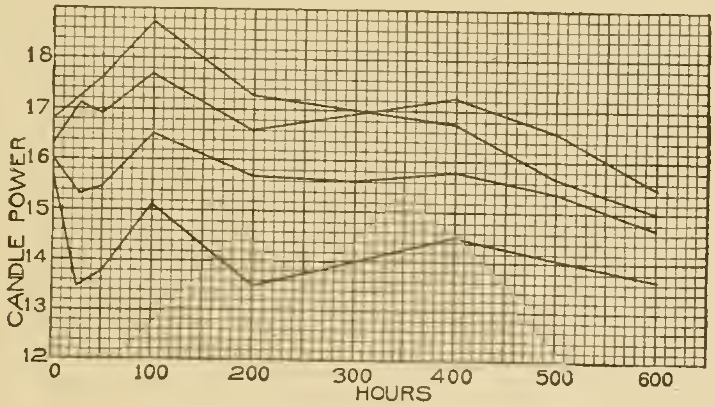


Fig. 6.

Lamps should always be renewed at the end of their useful life, this point being termed the "smashing-point", as it is cheaper to replace the lamp than to run it at the reduced candle-power. Some recommend running these lamps at a higher voltage, but that means at a reduced efficiency, and it is not good practice to do this.

Fig. 6 shows the life curves of a series of incandescent lamps. These curves show that there is an increase in the candle-power of some of the lamps during the first 100 hours, followed by a period during which the value is fairly constant, after which the light given by the lamp is gradually reduced to about 80% of the initial candle-power.

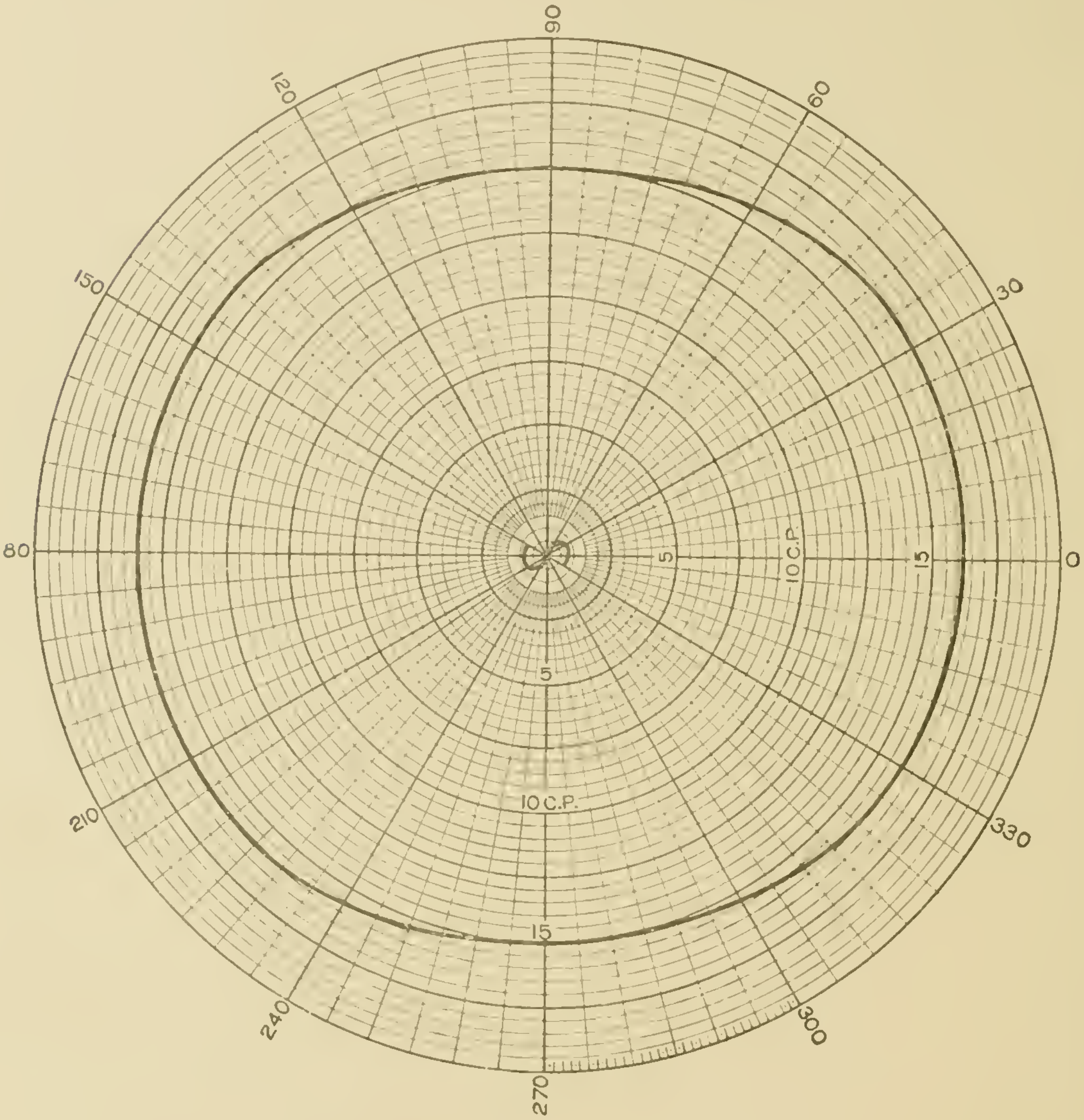


Fig. 7.

DISTRIBUTION OF LIGHT.

In Fig. 1 are shown various forms of filaments used in incandescent lamps, and Figs. 7 and 8 show the distribution of light from a single-loop filament of cylindrical cross-section.

Fig. 7 shows the distribution of light in a horizontal plane, the lamp being mounted in a vertical position, and Fig. 8 shows the distribution in a vertical plane. By changing the shape of the filament, the light distribution is varied. A mean of the readings taken in the horizontal plane forms the *mean horizontal candle-power*, and this candle-power rating is the one generally assumed for the ordinary incandescent lamp. A mean of the readings taken in a vertical plane gives us the mean vertical candle-power, but this value is of little use.

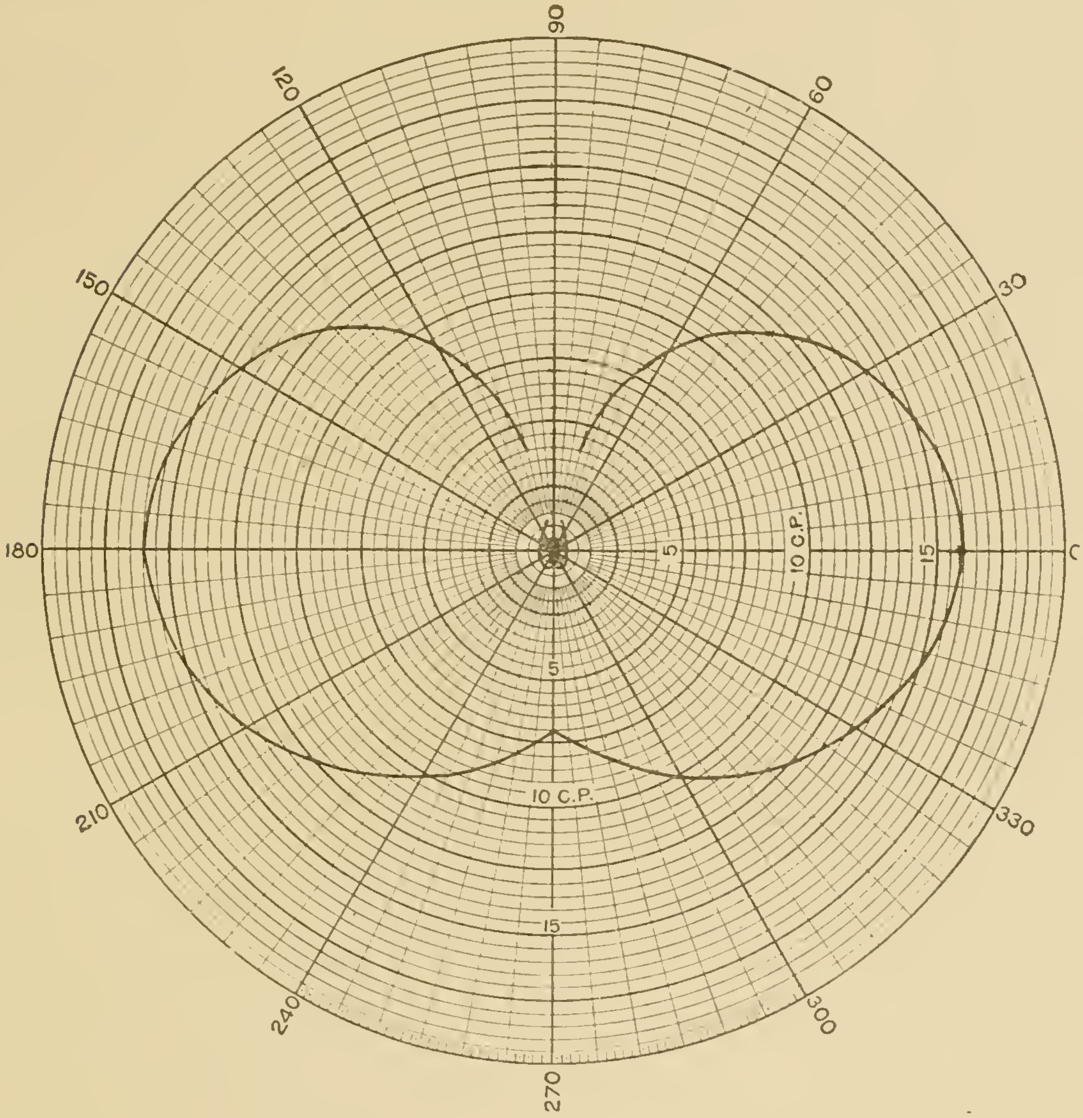


Fig. 8.

Mean Spherical Candle-Power. When comparing lamps which give an entirely different light distribution, the mean horizontal candle-power does not form a proper basis for such comparison, and the mean spherical or the mean hemispherical candle-power is used instead. By mean spherical candle-power is meant a mean value of the light taken in all directions. The methods for determining this will be taken up under *photometry*. The mean hemispherical candle-power has reference, usually, to the light given out below the horizontal plane.

ARC LAMPS.

The Electric Arc. Suppose two carbon rods are connected in an electric circuit, and the circuit closed by touching the tips of these rods together; on separating the carbons again the circuit will not be broken, provided the space between the carbons be not too great, but will be maintained through the arc formed at these points. This phenomenon, which is the basis of the arc light, was first observed on a large scale by Sir Humphrey Davy, who used a battery of 2,000 cells and produced an arc between charcoal points four inches apart.

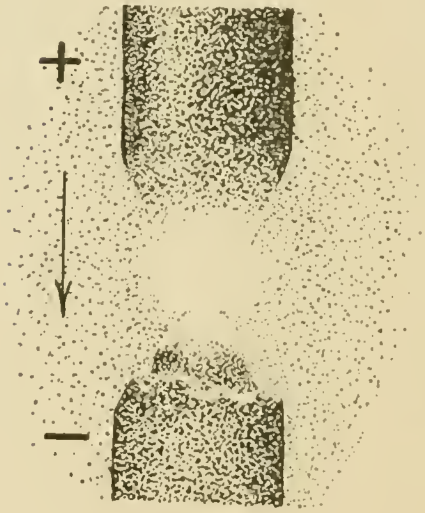


Fig. 9.

As the incandescence of the carbons across which an arc is maintained, together with the arc itself, forms the source of light for all arc lamps, it will be well to study the nature of the arc. Fig. 9 shows the general appearance of an arc between two carbon electrodes when maintained by direct current.

Here the current is assumed as passing from the top carbon to the bottom one as indicated by the arrow and signs. We find, in the direct-current arc, that the most of the light issues from the tip of the positive carbon, or electrode, and this portion is known as the *crater* of the arc. This crater has a temperature of from 3,000 to 3,500° C, the temperature at which the carbon vaporizes, and gives fully 80 to 85% of the light furnished by the arc. The negative carbon becomes pointed at the same time that the positive one is hollowed out to form the crater, and it is also incandescent but not to as great a degree as the positive carbon.

Between the electrodes there is a band of violet light, the arc proper, and this is surrounded by a luminous zone of a golden yellow color. The arc proper does not furnish more than 5% of the light emitted.

The carbons are worn away or consumed by the passage of the current, the positive carbon being consumed about twice as rapidly as the negative.

The light distribution curve of a *direct-current arc*, taken in a vertical plane, is shown in Fig. 10. Here it is seen that the maximum amount of light is given off at an angle of about 50° from the vertical, the negative carbon shutting off the rays of light that are thrown directly downward from the crater.

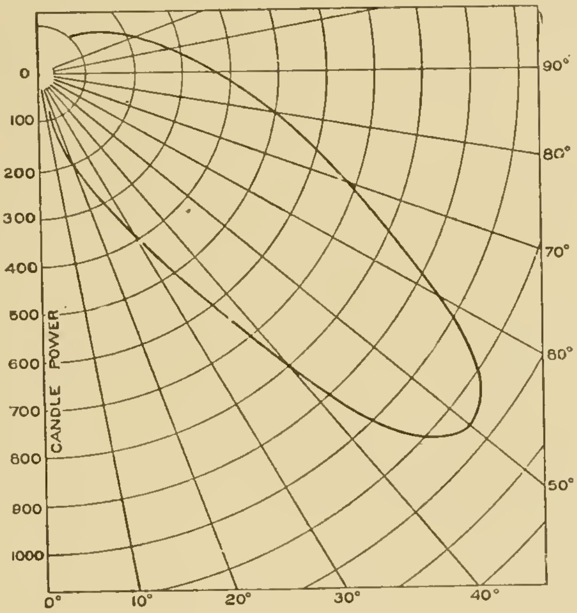


Fig. 10.

If alternating current is used, the upper carbon becomes positive and negative alternately, and there is no chance for a crater to be formed, both carbons giving off the same amount of light and being consumed at about the same rate. The light distribution curve of an *alternating-current arc* is shown in Fig. 11.

Arc Lamp Mechanisms. In a practical lamp we must have not only a pair of carbons for producing the arc, but also means for supporting these carbons, together with suitable arrangements for leading the current to them and for maintaining them at the proper distance apart. The carbons are kept separated the proper distance by the operating mechanisms which must perform the following functions:

1. The carbons must be in contact, or be brought into contact, to start the arc when the current first flows.
2. They must be separated at the right distance to form a proper arc immediately afterward.
3. The carbons must be fed to the arc as they are consumed.
4. The circuit should be open or closed when the carbons are entirely consumed, depending on the method of power distribution.

The feeding of the carbons may be done by hand, as is the case in some stereopticons using an arc, but for ordinary illumination the striking and maintaining of the arc must be automatic. It is made so in all cases by means of solenoids acting against the force of gravity or against springs. There are an endless number of such mechanisms, but a few only will be described here. They may be roughly divided into three classes:

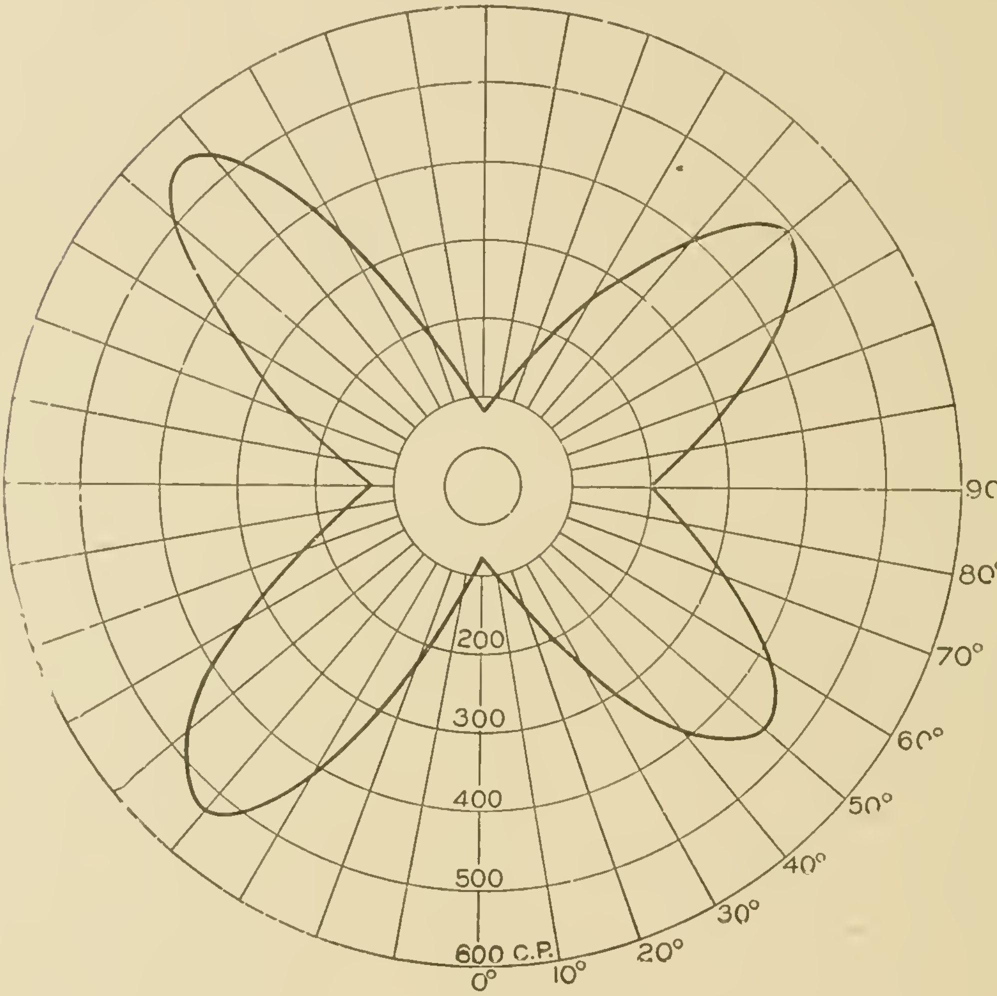
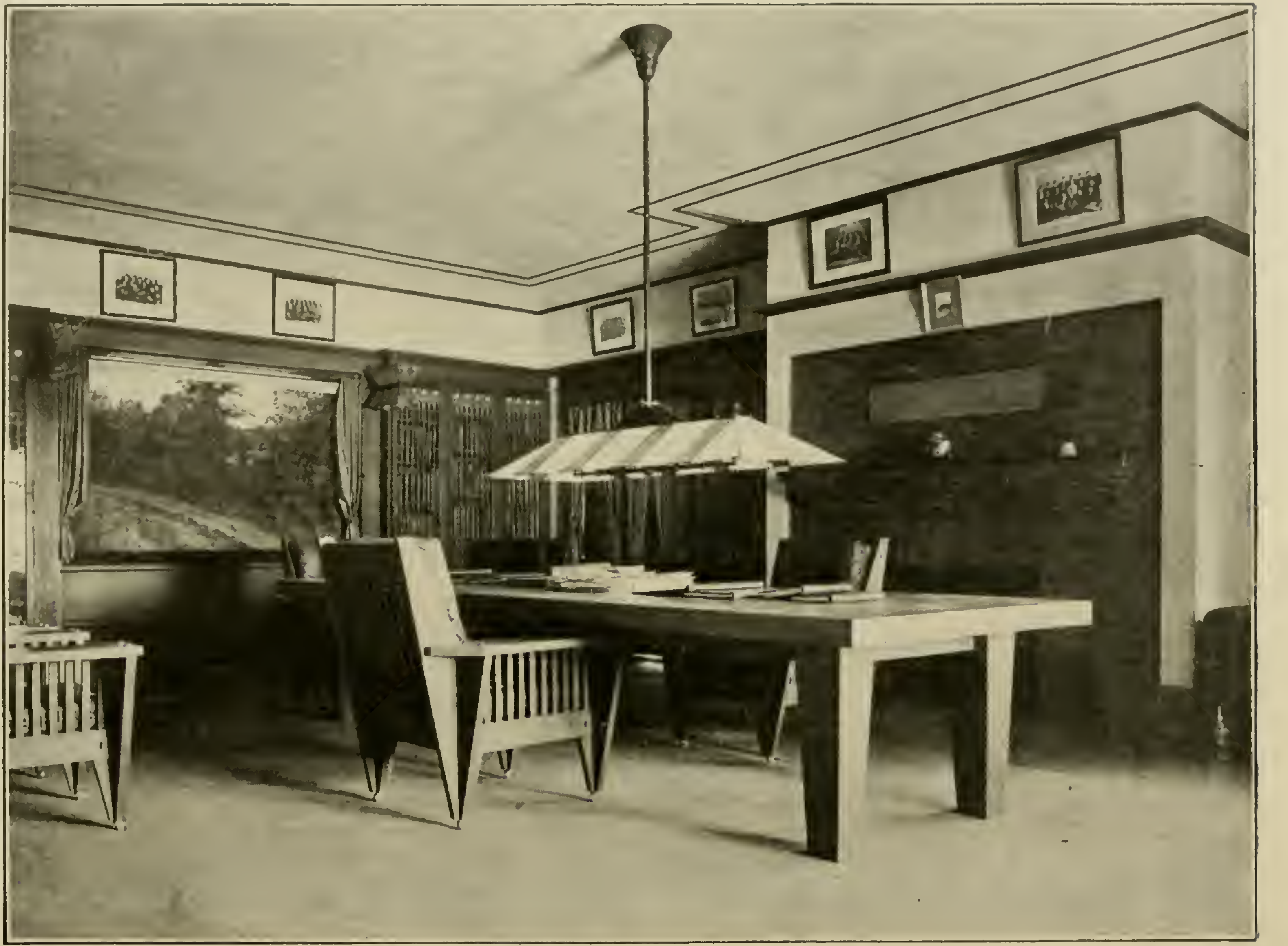


Fig. 11.

1. Shunt Mechanisms.
2. Series Mechanisms.
3. Differential Mechanisms.

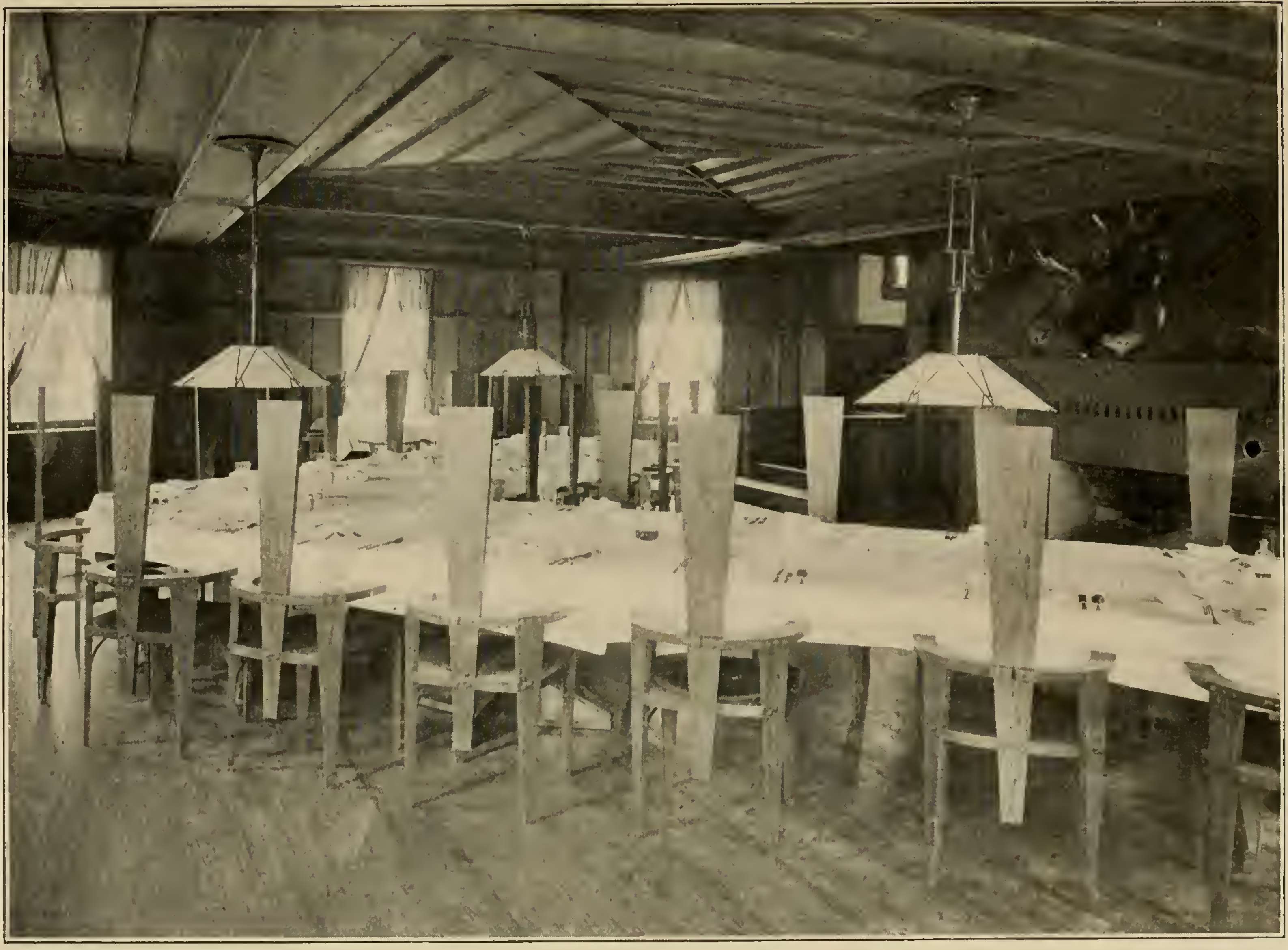
In **Shunt Lamps**, the carbons are held apart before the current is turned on, and the circuit is closed through a solenoid connected in across the gap so formed. All of the current must pass through this coil at first, and the plunger of the solenoid is



LIBRARY IN ALPHA DELTA PHI CHAPTER-HOUSE AT CORNELL UNIVERSITY, ITHACA, N. Y.

Dean & Dean, Architects, Chicago, Ill.

Stained and Waxed Cypress: Mantel of Teco-Ware Brick. Furniture Designed by the Architects. Leaded Glass Reading Lamp (Gas and Electric) over the Table. The Large Window-Sash Slides Up into the Wall. For Plans and Exterior, See Vol. III, Pages 282 and 298; for Other Interior, See Page 282 in this Volume.



DINING ROOM IN ALPHA DELTA PHI CHAPTER-HOUSE AT CORNELL UNIVERSITY, ITHACA, N. Y.

Dean & Dean, Architects, Chicago, Ill.

Oak Woodwork Stained a Dark Venetian Red; Mantel, Akron Roman Brick. Furniture Designed by Architects; Stained to Match the Woodwork.

arranged to draw the carbons together, thus starting the arc. The pull of the solenoid and that of the springs are adjusted to maintain the arc at its proper length.

Such lamps have the disadvantage of a high resistance at the start—450 ohms or more—and are difficult to start on series circuits, due to the high voltage required. They tend to maintain a constant voltage at the arc, but do not aid the dynamo in its regulation, so that the arcs are liable to be a little unsteady.

With the **Series-Lamp Mechanism**, the carbons are together when the lamp is first started and the current, flowing in the series coil, separates the electrodes, striking the arc. When the arc is too long, the resistance is increased and the current lowered so that the pull of the solenoid is weakened and the carbons feed together. This type of lamp can be used only on constant-potential systems.

Fig. 12 shows a diagram of the connection of such a lamp. This diagram is illustrative of the connection of one of the lamps manufactured by the Western Electric Company, for use with direct current on a constant-potential system. The symbols + and — refer to the terminals of the lamp, and the lamp must be so connected that the current flows from the top carbon to the bottom one. R is a series resistance, adjustable for different voltages by means of the shunt G. F and D are the controlling solenoids connected in series with the arc. B and C are the positive and negative carbons respectively, while A is the switch for turning the current on and off. H is the plunger of the solenoids and I the carbon clutch, this being what is known as a "carbon feed" lamp. The

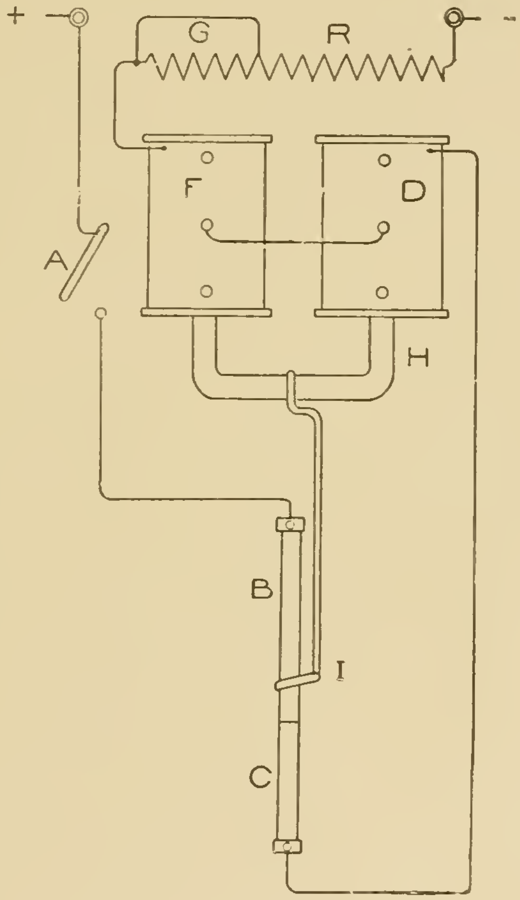


Fig. 12.

carbons are together when A is first closed, the current is excessive, and the plunger is drawn up into the solenoids, lifting the carbon B until the resistance of the arc lowers the current to such a value that the pull of the solenoid just counterbalances the weight of the plunger and carbon. G must be so adjusted that this point is reached when the arc is at its normal length.

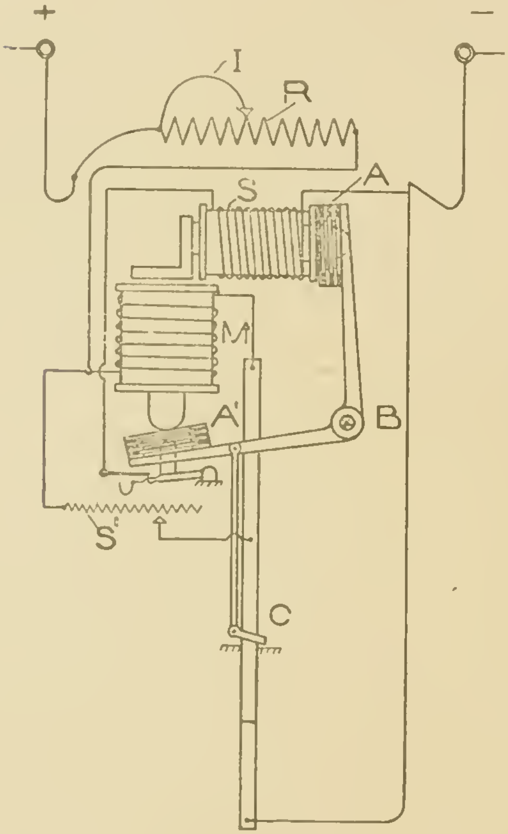


Fig. 13.

In the **Differential Lamp**, the series and shunt mechanisms are combined, the carbons being together at the start, and the series coil arranged so as to separate them while the shunt coil is connected across the arc, as before, to prevent the carbons from being drawn too far apart. This lamp operates only over a low-current range, but it tends to aid the generator in its regulation.

Fig. 13 shows a lamp having a differential control, this also being the diagram of a Western Electric Company arc lamp for direct-current, constant-potential system. Here S represents the shunt coil and M the series coil, the armature of the two magnets A and A′ being attached to a bell-crank, pivoted at B, and attached to the carbon clutch C. The pull of coil S tends to lower the carbon while that of M raises the carbon, and the two are so adjusted that equilibrium is reached when the arc is of the proper length. All of the lamps are fitted with an air dashpot or some damping device to prevent too rapid movements of the working parts.

The methods of supporting the carbons and feeding them to the arc may be divided into two classes:

1. Rod feed.
2. Carbon feed.

Lamps using a **Rod Feed** have the upper carbons supported by a conducting rod, and the regulating mechanism acts on this rod, the current being fed to the rod by means of a sliding contact. Fig. 14 shows the arrangement of this type of feed. The rod is shown at R, the sliding contact at B, and the carbon is attached to the rod at C.

These lamps have the advantage that carbons, which do not have a uniform cross-section or smooth exterior, may be used, but they possess the disadvantage of being very long in order to accommodate the rod. The rod must also be kept clean so as to make a good contact with the brush.

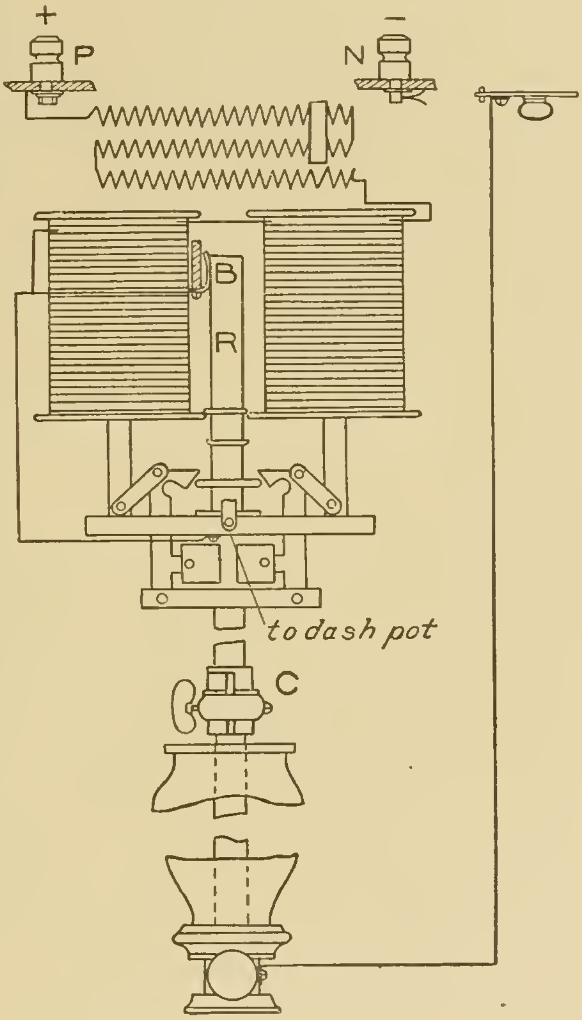


Fig. 14.

In **Carbon=Feed** lamps the controlling mechanism acts on the carbons directly through some form of clutch such as is shown at C in Fig. 15. This clamp grips the carbon when it is lifted, but allows the carbon to slip through it when the tension is released. For this type of feed the carbon must be straight and have a uniform cross-section as well as a smooth exterior. The current may be led to the carbon by means of a flexible lead and a short carbon holder.

Double=Carbon Lamps. In order to increase the life of the early form of arc lamp without using too long a carbon, the double-carbon type was introduced. This type uses two sets of carbons, both sets being fed by one mechanism so arranged that when one pair of the electrodes is consumed the other is put into service. With the introduction of the enclosed arcs, this form of lamp is rapidly disappearing, although a few are still in use.

Arc lamps are constructed to operate on *Direct Current* or *Alternating Current* systems when connected in *Series* or in *Multiple.* They are also made in both the *Open* and the *Enclosed* forms, but almost all of the lamps operating on alternating current or on constant-potential, direct current are enclosed.

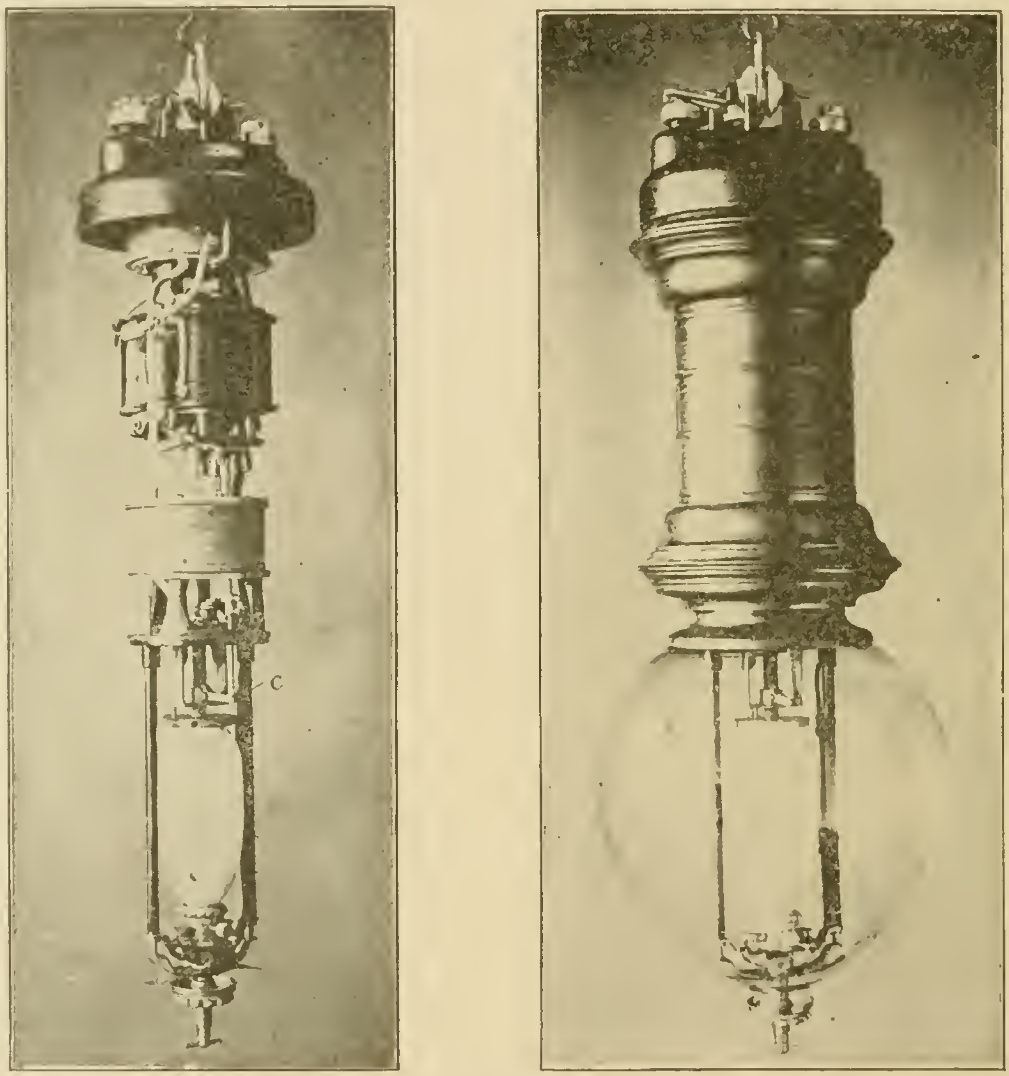


Fig. 15.

By an *Open Arc* is meant an arc lamp in which the arc is exposed to the atmosphere, while in the *Enclosed Arc* an inner or enclosing globe surrounds the arc, and this globe is covered with a cap which renders it nearly air-tight. Fig. 15 is a good example of an enclosed arc as manufactured by the General Electric Company.

Open Arcs for direct-current systems were the first to be used to any great extent, and they are used considerably at present, although they are being rapidly replaced by the enclosed types or the alternating-current systems. They are always connected in series, and are run from some form of special arc machine, a description of which may be found in "Types of Dynamo Electric Machinery".

Each lamp requires in the neighborhood of 50 volts for its operation, and, since the lamps are connected in series, the voltage of the system will depend on the number of lamps; therefore, the number of lamps that may be connected to one machine is limited by the maximum allowable voltage on that machine. By special construction as many as 125 lamps are run from one machine, but even this size of generator is not so efficient as one of greater capacity. Such generators are usually wound for 6.6 or 9.6 amperes. Since the carbons are exposed to the air at the arc, they are rapidly consumed, requiring that they be renewed daily for this type of lamp.

Enclosed Direct-Current Arc Lamps for series systems are constructed much the same as the open lamp, and are controlled by either shunt or differential mechanism. They require a voltage from 68 to 75 at the arc, and are usually constructed for from 5 to 6.8 amperes. They also require a constant-current generator.

Arc Lamps for Constant-Potential direct-current systems must have some resistance connected in series with them to keep the voltage at the arc at its proper value. This resistance is made adjustable so that the lamps may be used on any circuit. Its location is clearly shown in Fig. 15, one coil being located above, the other below the operating solenoids.

Arc Lamps for Alternating Currents do not differ greatly in construction from the direct-current arcs. When iron or other metal parts are used in the controlling mechanism, they must be laminated or so constructed as to keep down induced or eddy currents which might be set up in them. For this reason the metal spools, on which the solenoids are wound, are slotted at some point to prevent them from forming a closed secondary to the primary formed by the solenoid winding. On constant potential circuits a reactive coil is used in place of a part of the resistance for cutting down the voltage at the arc.

Interchangeable Arc Lamps are manufactured which may be readily adjusted so as to operate on either direct or alternating current, and on voltages from 110 to 220. Two lamps may be run in series on 220-volt circuits.

The distribution of light, and the resulting illumination for the different lamps just considered, will be taken up later. Aside from the distribution and quality of light, the enclosed arc has the advantage that the carbons are not consumed so rapidly as in the open lamp because the oxygen is soon exhausted from the inner globe and the combustion of the carbon is greatly decreased. They will burn from 80 to 100 hours without re-trimming.

TABLE 2.

		Watts Consumed.			Mean Intensity in H. U.			Mean Watts.		
					Spherical.		Lower Hemi-spherical	Spherical H. U.		Lower Hemi-spherical
D. C. Lamp.	Current.	In Lamp.	In Arc.	Mechanism.	Op. Outer.	Clear Outer	Clear Outer.	Op. Outer.	Clear Outer.	Clear Outer.
						235	332		2.37	1.66
1	5.01	551	401	150	172	256*	362*	3.10	2.18*	1 52*
3	5.08	559	406	252	195	216	282	2.85	2.60	1.99
4	4 76	524	381	143	127	139	208	4.12	3.76	2.52
5	4.[illegible]	458	333	125	151	171	221	2.96	2.63	2.07
7	4.76	521	381	113	203	333	317	2.63	2.20	1.65
9	4.81	532	387	115	182	226	281	2.83	2.38	1.89
10	4.99	549	399	150	202	242	309	2.71	2.21	1.77
12	4.87	536	390	146	178	195	230	3.05	2.66	2.33
Mean	4.9	529	384	144	176	207	272	3.03	2.60	1.98

A. C. Lamp.	Current.	In Lamp.	Power Factor Lamp.	In Arc.	Power Factor Arc.	Mechanism.						
101	6.40	448	.63	310	.82	108	127	141	206	3.52	2.17	2.17
								203	236		2.26	1.91
102	6.79	459	.61	375	.73	81	116	176†	226†	3.31	2.60†	1 72†
103	5.89	424	.65	311	.75	80	116	130	147	3.66	3.15	2.88
105	6.20	414	.61	382	.80	32	128	187	219	3.24	2.20	1.89
								153	169		2.56	2.23
106	6.12	378	.56	298	.70	80	132	182†	281	2.82	2.19†	1.48†
108	6.48	457	.61	383	.80	71.5	133	175	211	3.20	2.61	2.16
110	6.18	339	.49	276	.72	63	140*	126	113	2.41*	2.68	2.37
Mean	6.29	417	.60	342	.76	74.5	130	159	190	3.31	2.66	2.23

*Condition of no outer globe. †Condition with shade on lamp. H. U Hefner Units.

Rating of Arc Lamps. Open arcs have been classified as follows:

Full Arcs, 2,000 candle-power taking 9.5 to 10 amps. or 450–480 watts.
Half Arcs, 1,200 candle-power taking 6.5 to 7 amps. or 325–350 watts.

These candle-power ratings are much too high, and run more nearly 1,200 and 700, respectively, for the point of maximum intensity and less than this if the mean spherical candle-power be taken. For this reason, the ampere or watt rating is now used to indicate the power of the lamp. Enclosed arcs use from 3 to 6.5 amperes, but the voltage at the arc is higher than for the open lamp. Table 2 gives some data on enclosed arcs on constant-potential circuits.

Efficiency. The efficiency of arc lamps is given as follows:

Direct Current Arc (enclosed) 2.9 watts per candle-power.
Alternating Current Arc (enclosed) 2.95 watts per candle-power.
Direct Current Arc (open) .6-1.25 watts per candle-power.

Arc-Lamp Carbons are either moulded or forced from a product known as petroleum coke or from similar materials such as lampblack. The material is thoroughly dried by heating to a high temperature, then ground to a fine powder and combined with some substance such as pitch which binds the fine particles of carbon together. After this mixture is again ground it is ready for moulding. The powder is put in steel moulds and heated until it takes the form of a paste, when the necessary pressure is applied to the moulds. For the forced carbons, the powder is formed into cylinders which are placed in machines which force the material through a die so arranged as to give the desired diameter. The forced carbons are often made with a core of some special material, this core being added after the carbon proper has been finished. The carbons, whether moulded or forced, must be carefully baked to drive off all volatile matter. The forced carbon is always more uniform in quality and cross-section, and is the type of carbon which must be used in the carbon feed lamp. The adding of a core of a different material seems to change the quality of light, and being more readily volatilized, keeps the arc from wandering.

Plating of carbons with copper is sometimes resorted to for moulded forms for the purpose of increasing the conductivity, and, by protecting the carbon near the arc, prolonging the life.

SPECIAL LAMPS.

Under this heading may be considered all lamps which do not use carbon as the incandescent material, as well as some lamps

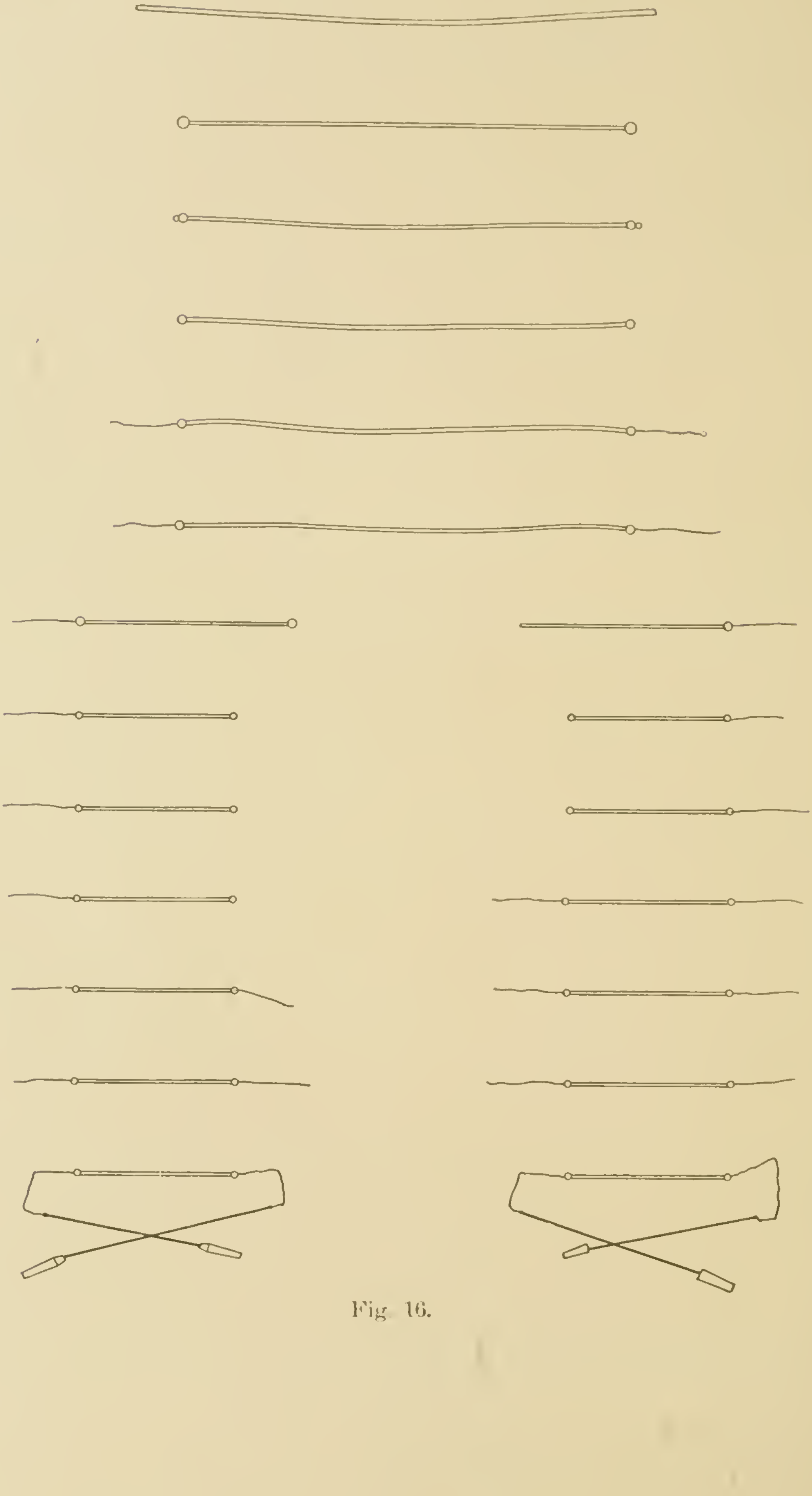


Fig. 16.

which use carbon in conjunction with other materials. The first of these lamps, or the one at present most widely used, is the Nernst Lamp.

The Nernst Lamp is an incandescent lamp using for the incandescent material certain oxides of the rare earths. The oxide is mixed in the form of a paste, then squirted through a die into a string which is subjected to a roasting process forming the filament or *glower* material of the lamp. The glowers are cut the desired length and platinum terminals attached. The attachment of these terminals to the glowers is a very important process in the manufacture of the lamp, and is accomplished by fusing the ends of the glower and the platinum lead into small beads, and, when the two are brought into contact, the platinum is sucked up into the glower head, forming a very neat and efficient connection. Fig. 16 shows several completed glowers.

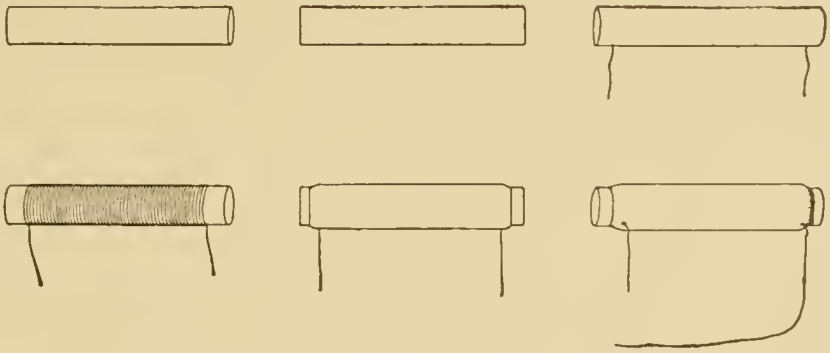


Fig. 17.

As the glower is a non-conductor when cold, some form of *heater* is necessary to bring it up to a temperature at which it will conduct. Two forms of heater are used, the first being formed of fine platinum wire wound over a porcelain tube as a support and covered with porcelain paste to prevent deterioration as much as possible. These "heater tubes", as they are called, are mounted just above the glowers in the finished lamp. The second form of heater is known as the "spiral heater", and this is also made of fine platinum wire wound on a porcelain rod and covered with paste, the rod being then formed on a mandrel to the desired shape. Figs. 17 and 18 show the two forms of heaters.

The heating device is connected across the circuit when the lamp is first turned on, and it must be cut out of circuit automatically when the glower becomes a conductor, otherwise the heater would soon be destroyed. This automatic *cut-out* is operated by means of an electromagnet so arranged that current flows through its coil as soon as the glower conducts and opens a form of silver contact cutting out the heater. The heater circuit is normally kept closed by the force of gravity so that the lamps will operate only in one position. A successful form of universal cut-out, that is, one which will operate when the lamp is in any position, has not yet been put on the market, though experiments with this type are being made.

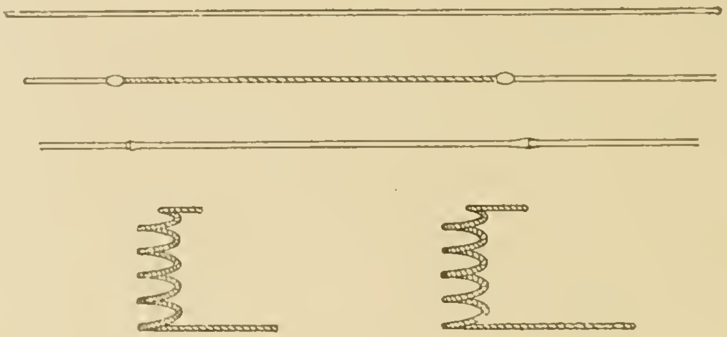


Fig. 18.

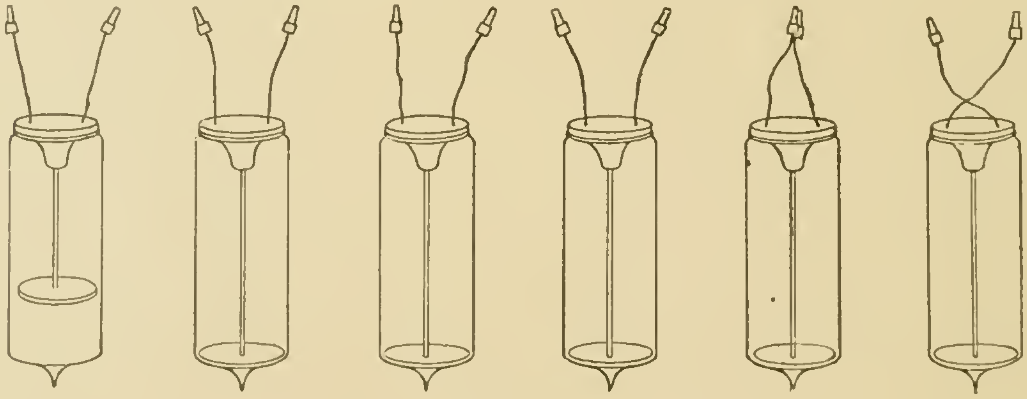


Fig. 19.

The conductivity of the glower increases with its temperature; hence, if used on a constant-potential circuit directly, its temperature would continue to increase, due to the greater current flowing, until the glower was destroyed. To prevent this increase of current, a *ballast resistance* of fine iron wire is connected in series with the glower. As is well known, the resistance of iron wire increases quite rapidly with increase of temperature, and this resistance is so adjusted that the resistance of the combined circuit reaches a constant value when the current is of the proper strength. The iron wire must be protected from the air to prevent oxidization and too rapid temperature changes, and, for this reason, it is mounted in a glass bulb filled with hydrogen. Hydrogen has been selected for this purpose because it is an inert gas and conducts the heat from the ballast to the walls of the bulb better than other gases. Fig. 19 shows the form of bulb which contains the ballast.

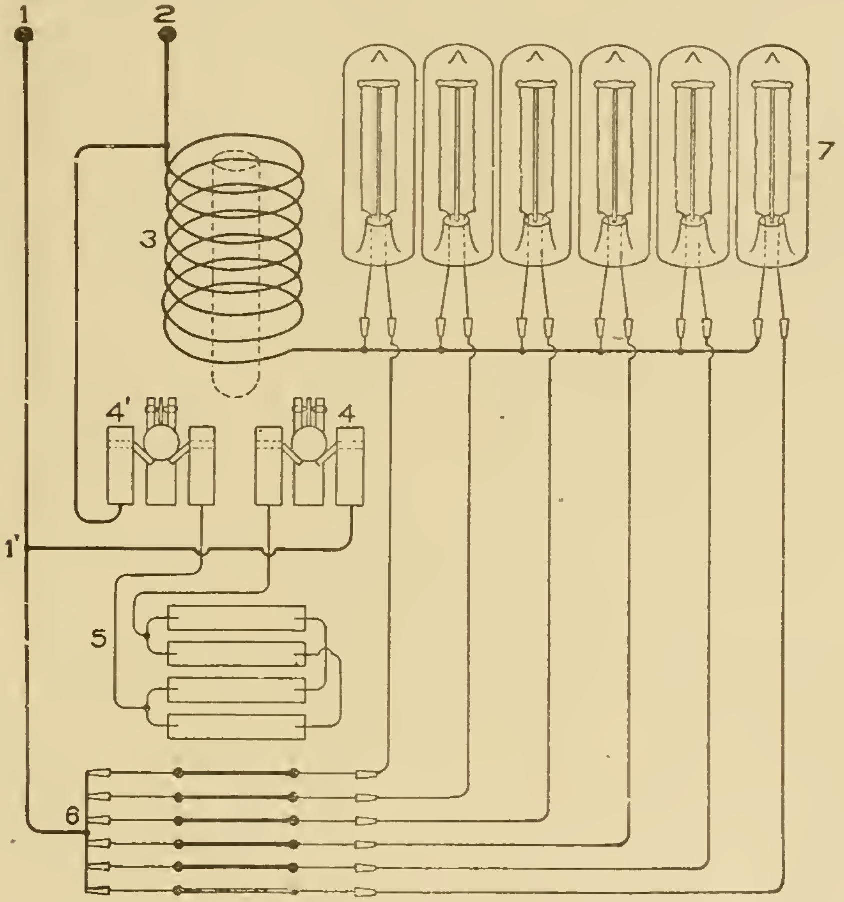


Fig. 20.

All of the parts enumerated, namely, glower, heater, cut-out and ballast, are mounted in a suitable manner, the smaller lamps having but one glower and arranged to fit an incandescent lamp socket, while the larger types have as many as six glowers and are arranged to be supported in a manner similar to arc lamps. All of the parts are interchangeable and may be easily renewed.

Fig. 20 shows the complete connections of a six-glower lamp. Current enters the lamp at terminal 1 (or 2), passes through the

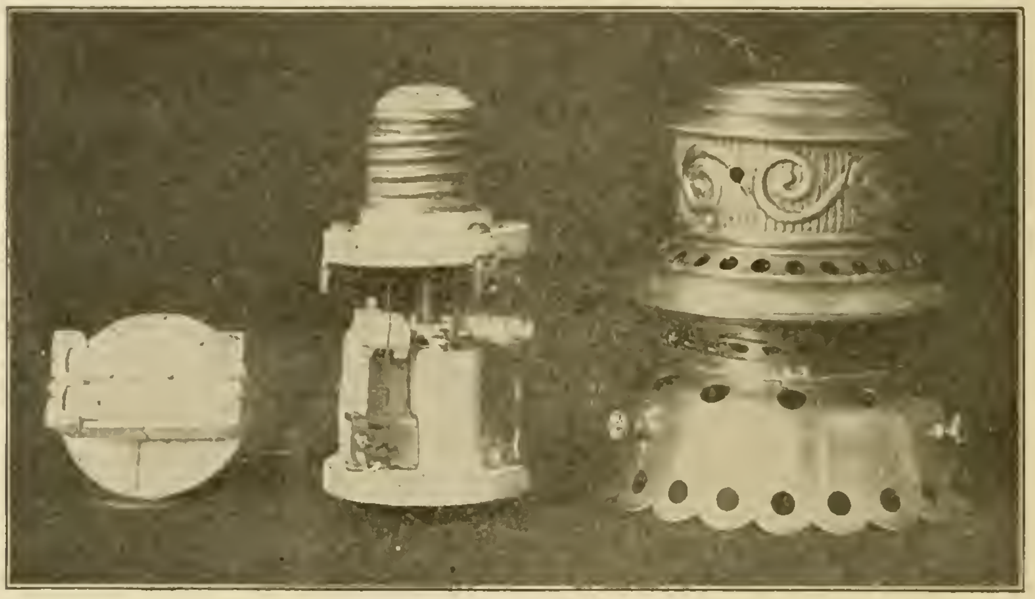


Fig. 21.

contacts of the cut-out 4, to the heater circuit 5, then to the contacts 4′ and to terminal 2. When the glowers become hot enough to conduct, the current divides at 1′, part of it going through the glowers 6, the ballast 7, and the cut-out coil 3 to terminal 2. By the time the current in the glower has reached its normal value, the contacts at 4 and 4′ have opened, cutting out the heater coils

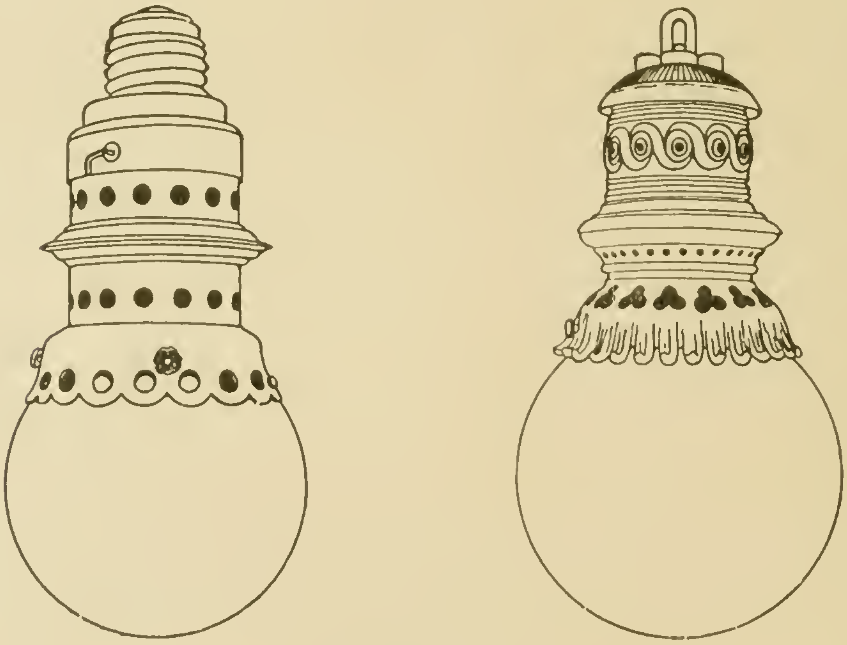


Fig. 23.

entirely. The heaters are so arranged that if one is destroyed, the other two will heat the glowers as quickly as possible.

Fig. 21 shows the parts of a single-glower lamp with the exception of the globe. Fig. 22 illustrates a six-glower street lamp. Fig. 23 shows lamps for inside use completely assembled Fig. 24 shows a glower and spiral heater so mounted that the two may be very readily replaced. This type is used on some of the very latest forms of lamps put on the market by the Nernst Lamp Company of Pittsburg, which company controls the manufacture of these lamps in the United States.

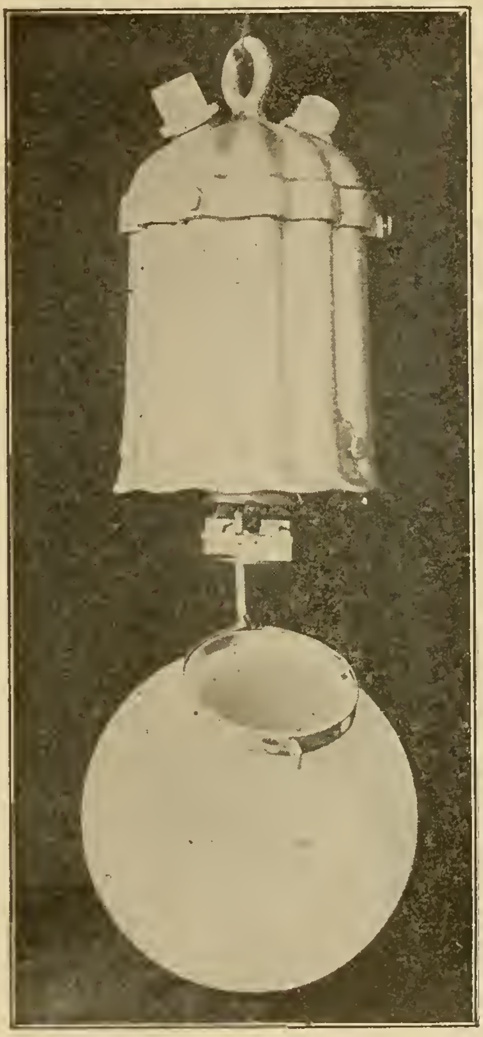


Fig. 22.

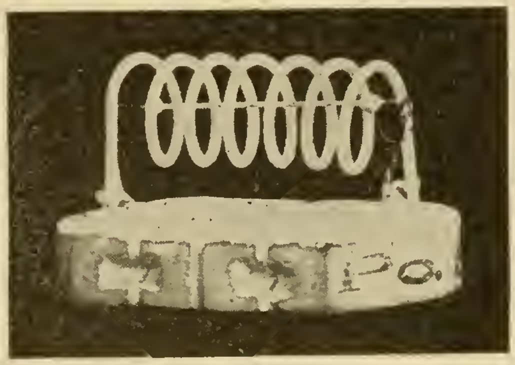


Fig. 24.

This type of lamp is used extensively only on alternating-current circuits at a frequency of about 60 cycles, and preferably at 220 volts, as the efficiency is better at this voltage, due to less energy being consumed in the ballast. Series lamps, and lamps operated on direct current, are still in the experimental stage.

The advantages claimed for the Nernst lamp are increased efficiency, a good color of light, and a good light distribution. The efficiency varies with the type and the voltage used, as well as with the direction in which the candle-power is measured and the type of globe used. For a 100-hour run on a two-glower, 220-volt lamp using a 6-inch light sand-blasted globe, the watts varied from 170 to 158, while the mean hemispherical candle-power varied from 67.8 to 50.8, giving an efficiency from 2.5 to 3.1 watts per mean hemispherical candle-power; showing an efficiency better than the incandescent but not so good as the arc lamp.

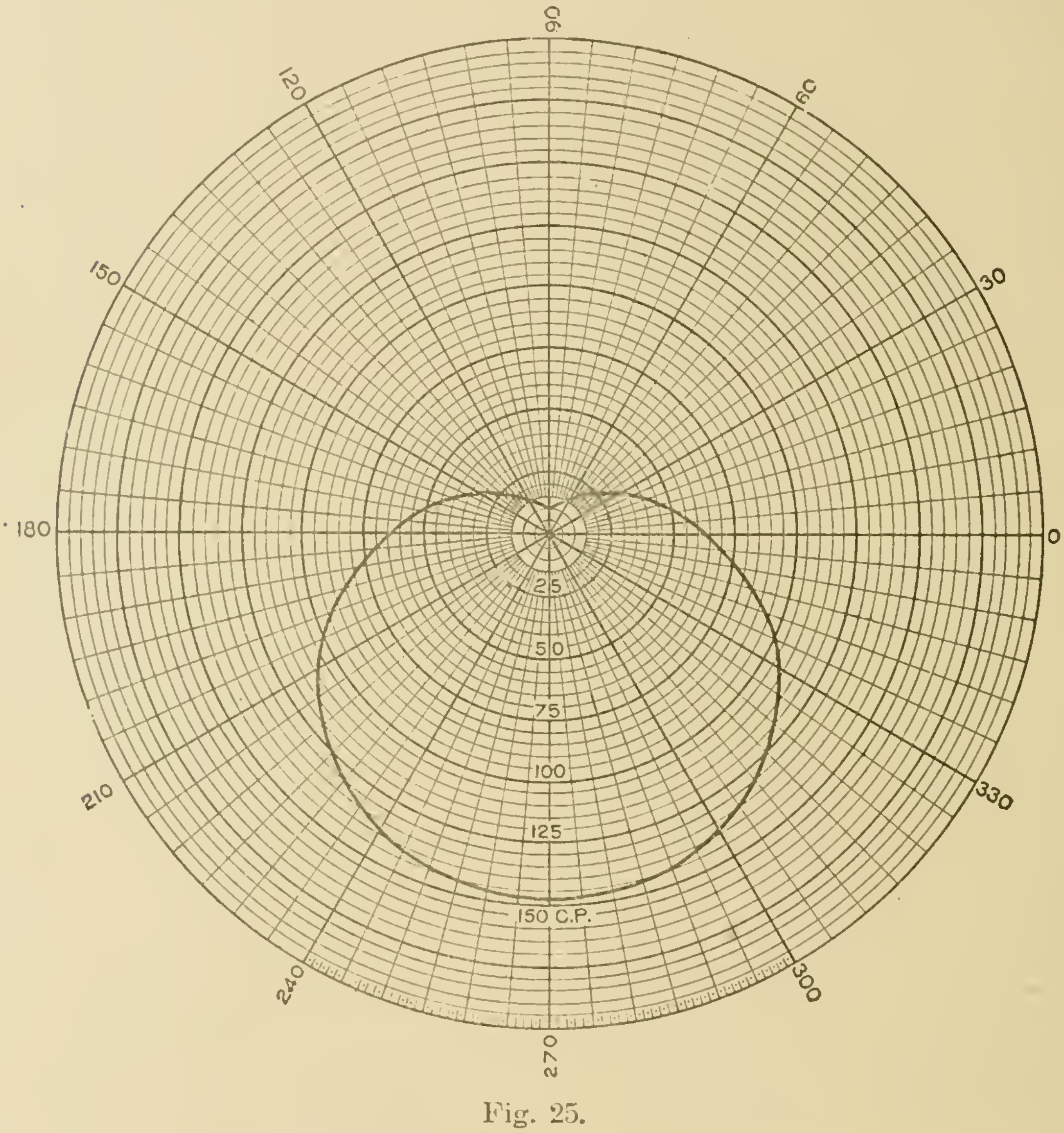


Fig. 25.

Fig. 25 shows two distribution curves for Nernst lamps.

To give the best results, lamps using the tube heaters must be cleaned regularly at the intervals of about 100 hours of burning. The spiral heaters are not cleaned, but are renewed at the end of the useful life of the glower. The light given by these lamps is very white in color, and the use of sand-blasted or alabaster globes reduces its intense brilliancy.

Osmium Lamps. Osmium has been experimented on as a substance to replace carbon in the ordinary incandescent lamp, and so far very efficient lamps have been constructed using this material, but the voltage is low, due to the low resistance of the material and the difficulty of making a filament fine enough to give the desired resistance for higher voltages. At 25 volts, lamps are constructed giving an efficiency of 1.5 to 1.7 watts per candle-power, and with a life comparable with that of a 3.5-watt incandescent lamp. The low voltage makes this lamp undesirable for parallel distribution systems.

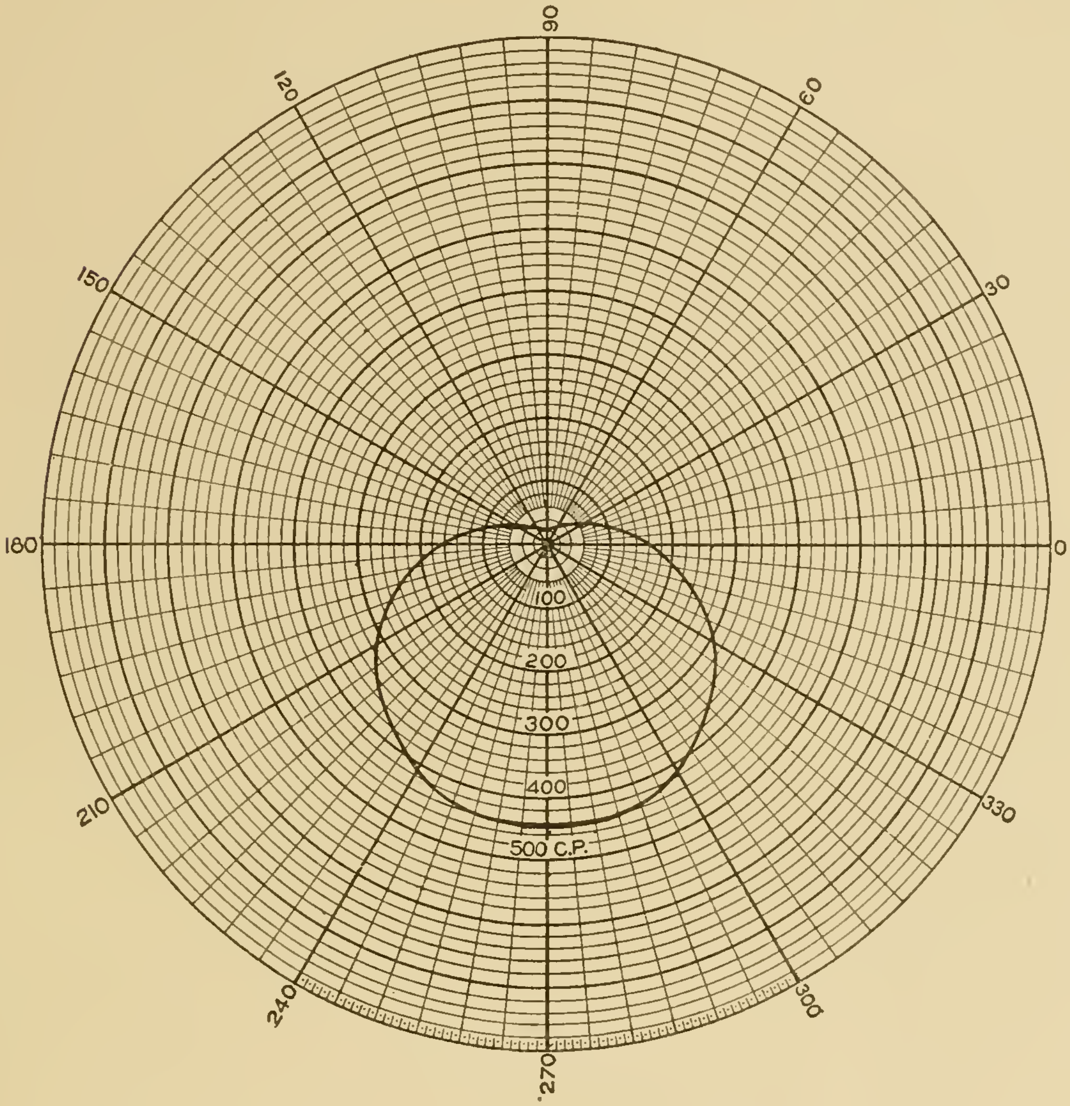


Fig. 25.

The Bremer Arc Lamp is one of the most favorable of several modifications of the arcs which have been proposed. This lamp uses very slender carbons having a core made of refractory oxides such as silica, lime, or magnesia. An efficiency of .1 to .4 watts per candle-power (mean spherical) has been claimed for this type of lamp, but it is still in the experimental stage.

The Mercury Vapor Lamp. Probably the Cooper Hewitt, or Mercury Vapor Lamp, is the only other special lamp deserving mention here. This lamp is being introduced to quite an extent where the quality of the light is not of so much importance. In this lamp, mercury vapor, rendered incandescent by the passage of an electric current, forms the source of light. One electrode is formed of mercury and the other may be of mercury or iron. In the more common type of lamp, these electrodes are mounted at the end of a long glass tube which has been very carefully exhausted. Fig. 26 shows such a lamp constructed for a 110-volt circuit. Dimensions of this lamp are as follows:

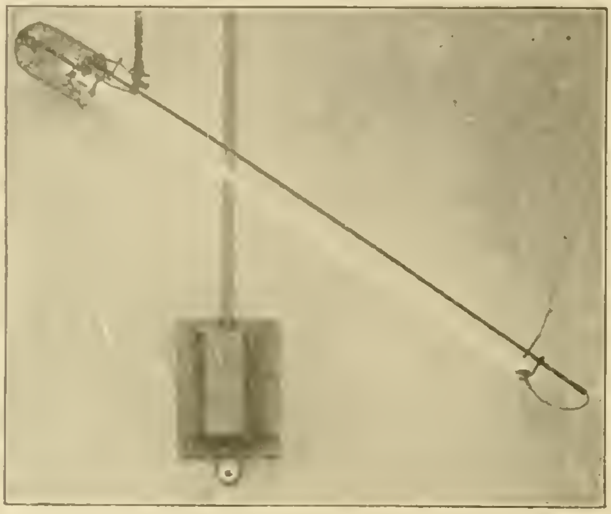
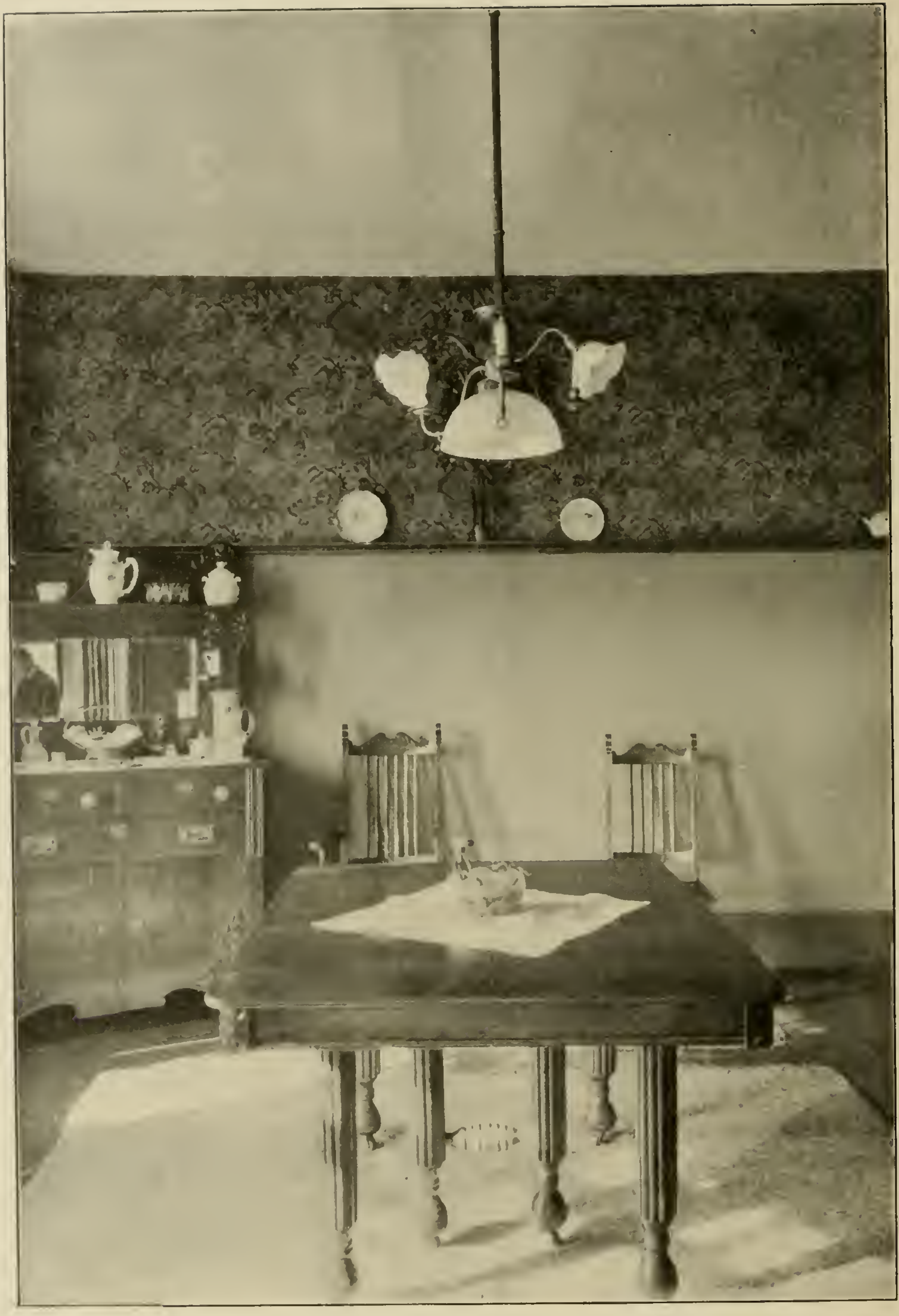


Fig. 26.

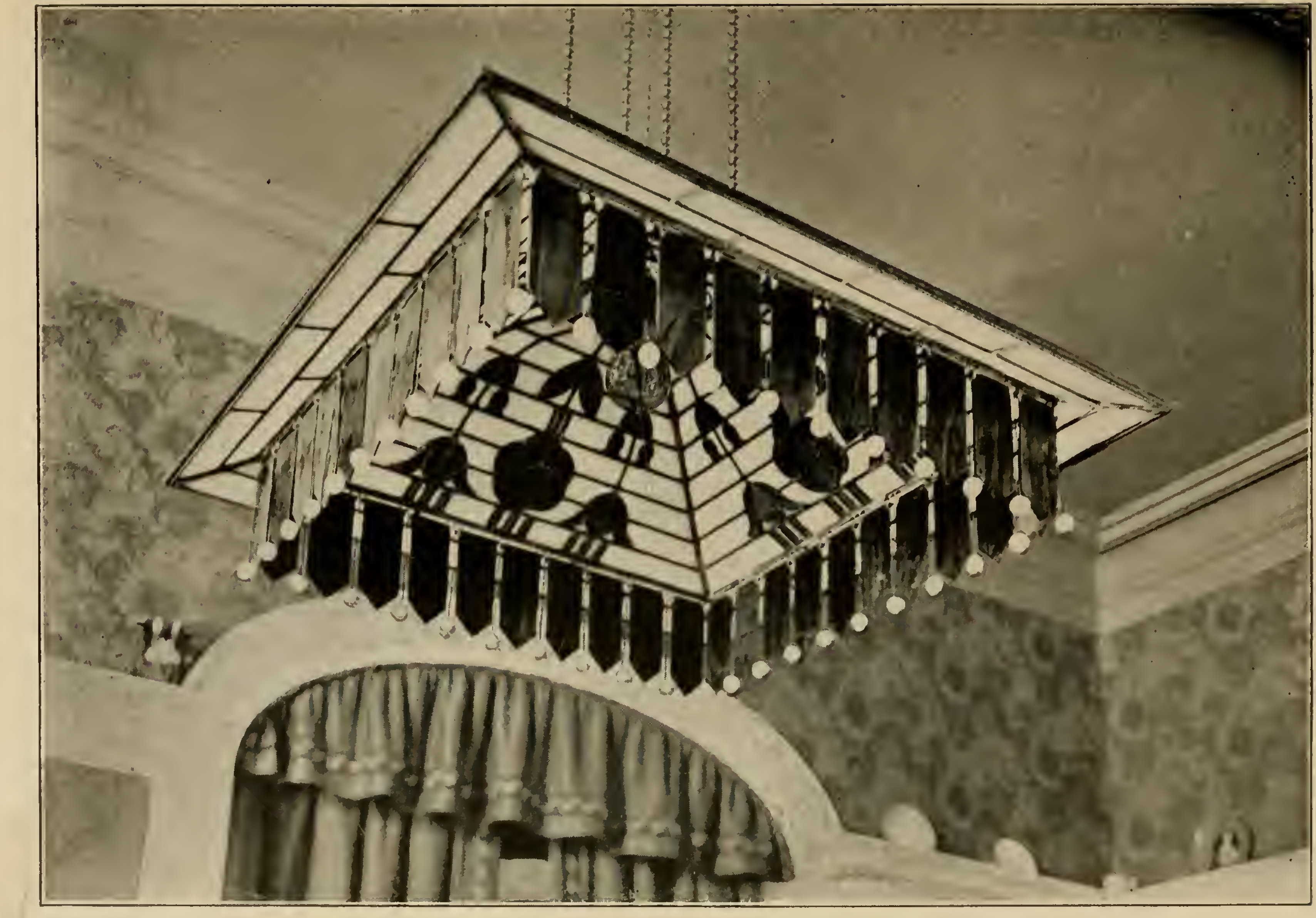
	For 100 Volts.	For 120 Volts.
Length of light-giving tube.......	43 inches.	49 inches.
Length over all..................	50 inches.	56 inches.
Diameter	1 inch.	

Current 3 to 3.5 amperes.
Candle Power at 120 volts, 750.
Life (average), 1,600 hours.

The mercury vapor, at the start, may be formed in two ways. First, the lamp may be tipped so that a stream of mercury makes contact between the two electrodes and mercury is vaporized when the stream breaks. Second, by means of a high inductance and a quick break switch; a very high voltage, sufficient to pass current from one electrode to the other, is induced and the conducting vapor formed. The lamp, as now manufactured, will operate only on direct current, but the alternating-current lamp is being developed.



SIMPLE COMBINATION GAS AND ELECTRIC FIXTURE IN A DINING ROOM



DETAIL OF DINING-ROOM TABLE LANTERN IN HOUSE AT WAUKEGAN, ILL.

R. C. Spencer, Jr., Architect, Chicago, Ill.

Fig 27 is a diagram of a lamp connected for starting by the quick-break method, while Fig. 28 shows two 55-volt lamps connected in series on a 110-volt circuit, and arranged to be started by tipping. A steadying resistance and reactance are connected as shown in the diagram, the two being mounted on one base which may readily be attached to the wall as shown in Fig. 26.

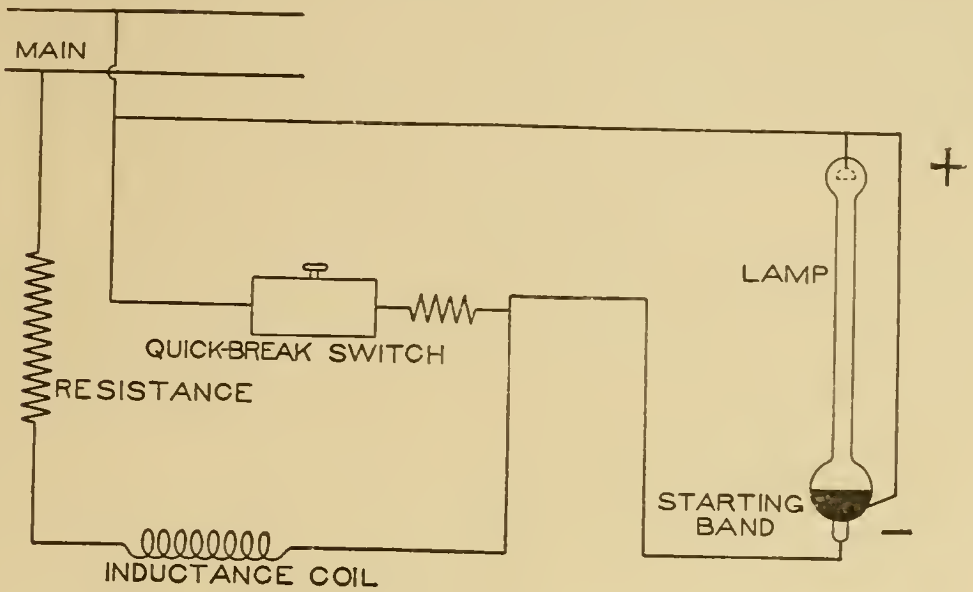


Fig. 27.

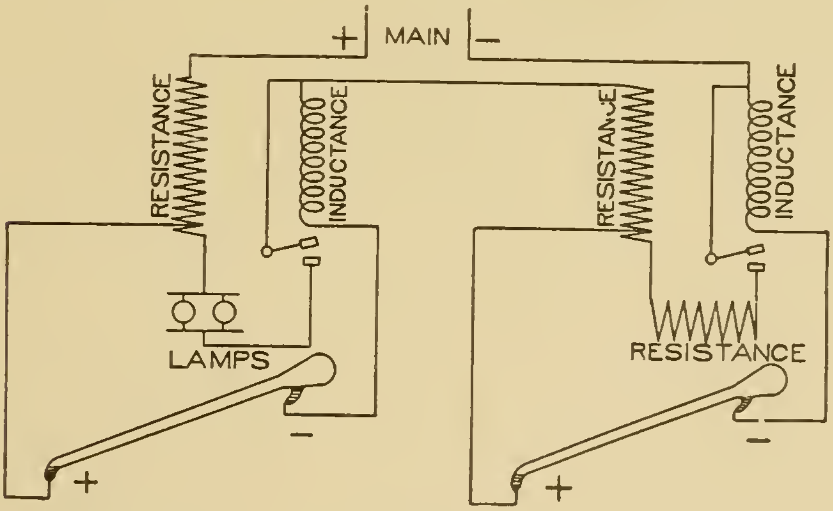


Fig. 28.

The mercury vapor lamp is not made in small sizes for ordinary voltages, and its light is very objectionable for the purpose of distinguishing color, as there is an entire absence of red rays.

This absence of the red light makes the illumination one that is very easy on the eyes but, on account of the color, its use is limited to the lighting of shops, offices, and drafting rooms, or in display windows where the goods shown are not changed in appearance by its color. It is also coming into use to a large extent in photographic work on account of the actinic properties of its light.

POWER DISTRIBUTION.

The question of power distribution for electric lamps and other appliances is taken up fully in the section on that subject, therefore it will be treated very briefly here. The systems may be divided into:

1. Series Distribution Systems.
2. Multiple-Series or Series-Multiple Systems.
3. Multiple or Parallel Systems.

They apply to both alternating and direct current.

The Series System is the most simple of the three; the lamps, as the name indicates, being connected in series as shown in Fig. 29. A constant load is necessary if a constant potential is to be used. If the load is variable, a constant-current generator, forms of which are described in "Types of Dynamo-Electric Machinery", or a special regulating device is necessary. Such devices are constant-current transformers and constant-current regulators as applied to alternating-current circuits.

The series system is used mostly for arc and incandescent lamps when applied to street illumination. Its advantages are simplicity and saving of copper. Its disadvantages are high voltage, fixed by the number of lamps in series; size of machines is limited since they cannot be insulated for voltage above about 6,000; a single open circuit shuts down the whole system.

Alternating-current series distribution systems are being used to a very large extent. By the aid of special transformers, or regulators, any number of circuits can be run from one machine or set of bus bars, and apparatus can be built for any voltage and of any size. It is not customary, however, to build transformers of this type having a capacity greater than 100, 6.6-ampere lamps.

The constant-current transformer most in use for lighting purposes is the one manufactured by the General Electric Company and commonly known as a "tub" transformer. Fig. 30 shows such a transformer when removed from the case, and Fig. 29 gives a diagram of the connection of a single-coil transformer in service.

Referring to Fig. 30, the fixed coils A form the primaries which are connected across the line; the movable coils B are the secondaries connected to the lamps. There is a repulsion of the coils B by the coils A when the current flows in both circuits and this force is balanced by means of the weights at W, so that the coils B take a position such that the normal current will flow in the secondary. On light loads, a low voltage is sufficient, hence the secondary coils are close together near the middle of the machine and there is a heavy magnetic leakage. When all of the lamps are on, the coils take the position shown when the leakage is a minimum and the voltage a maximum. When first starting up, the transformer is short-circuited and the secondary coils brought close together. The short circuit is then removed and the coils take a position corresponding to the load on the line.

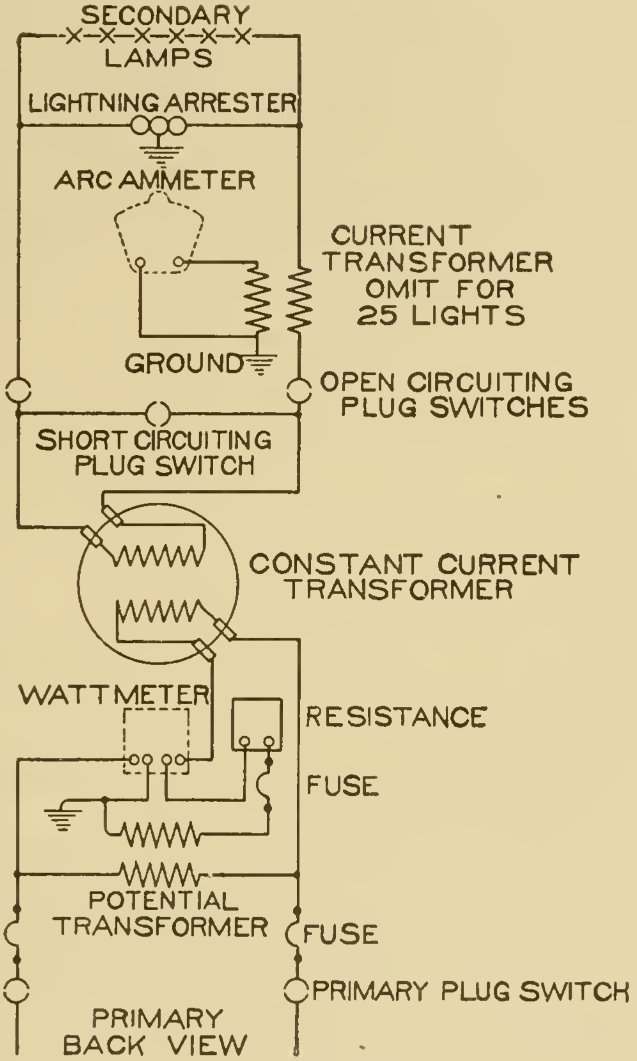


Fig. 29.

These transformers regulate from full load to $\frac{1}{3}$ rated load within $\frac{1}{10}$ ampere of normal current, and can be run on short circuit for several hours without overheating. The efficiency is given as 96% for 100-light transformers and 94.6% for 50-light transformers at full load. The power factor of the system is from

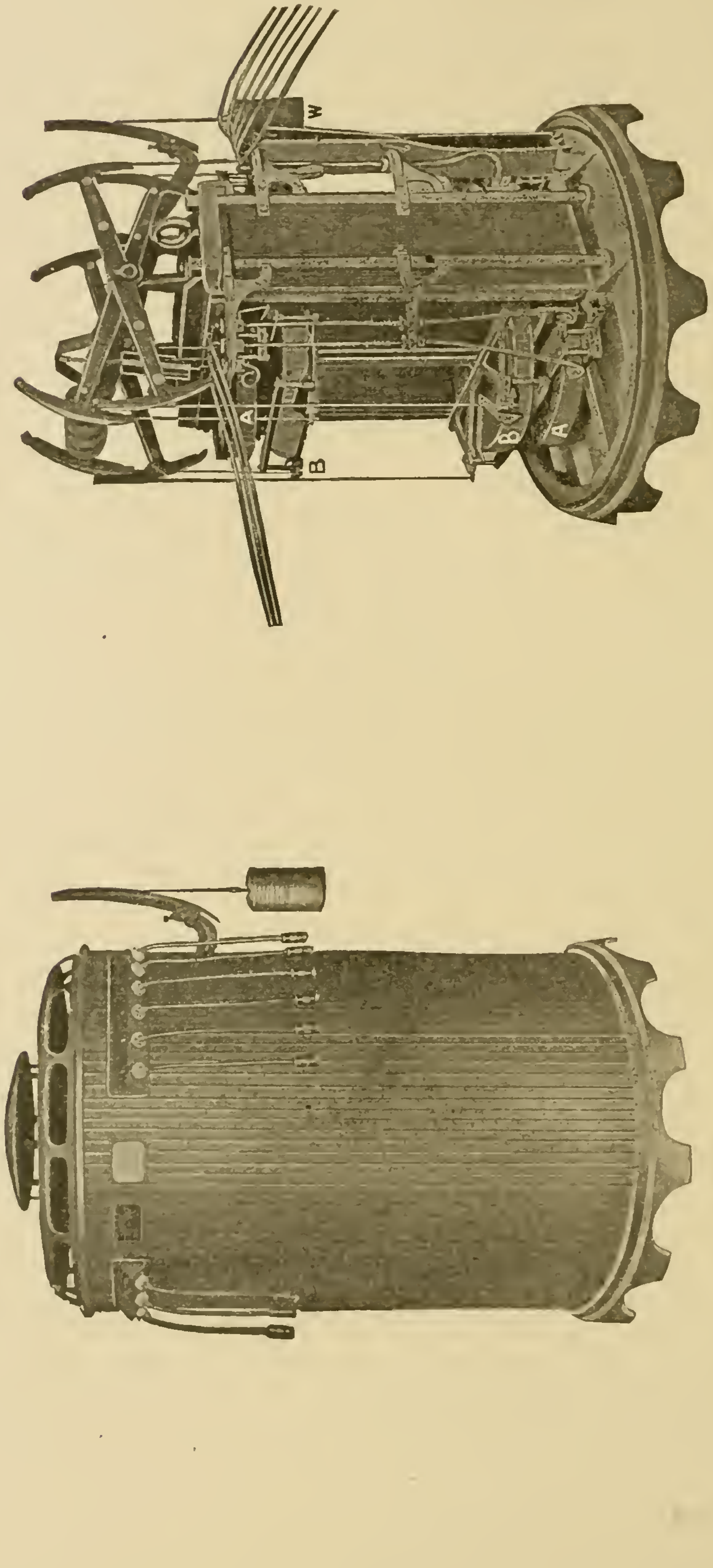


Fig. 30.

76 to 78% on full load, and, owing to the great amount of magnetic leakage at less than full load, the effect of leakage being the same as the effect of an inductance in the primary, the power factor is greatly reduced, falling to 62% at $\frac{3}{4}$ load, 44% at $\frac{1}{2}$ load, and 24% at $\frac{1}{4}$ load.

Standard sizes are for capacities of 25, 35, 50, 75, and 100, 6.6 ampere enclosed arcs. The low power factor of such a system on light loads shows that a transformer should be selected of such a capacity that it will be fully or nearly fully loaded at all times. The primary winding can be constructed for any voltage and the open circuit voltages of the secondaries are as follows:

25	light	transformer,	2300	volts.
35	“	“	3200	“
50	“	“	4600	“
75	“	“	6900	“
100	“	“	9200	“

The 50-, 75-, and 100-light transformers are arranged for multiple circuit operation, two circuits used in multiple, and the voltages at full load reach 4,100 for each circuit on the 100-light machine.

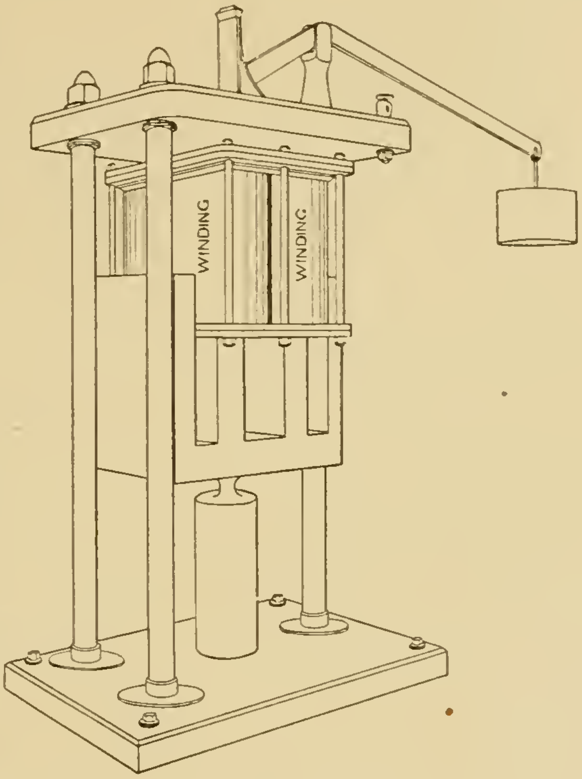


Fig. 31.

The second system, used for series distribution on alternating-current circuits, consists of a constant-potential transformer, stepping down the line voltage to that required for the total number of lamps on the system, allowing 83 volts for each lamp, and in series with the lamps is a reactive coil, the reactance of which is automatically regulated, as the load is increased or decreased, in order to keep the current in the line constant. Fig. 31 shows such a regulator as manufactured by the General Incandescent Arc Light Company, and Fig. 32 shows this regulator connected in circuit. The inductance is varied by the movement of the coil to include more or less iron in the magnetic circuit. Since the inductance in series with the lamps is high on light loads, the power factor is greatly reduced as in the constant-current transformer; and the circuits should, preferably, be run fully loaded. 60 to 65 lamps on a circuit is the maximum limit.

While used primarily for arc-light circuits, the same systems, designed for lower currents, are very readily applied to series incandescent systems.

Multiple-series and series-multiple systems combine several lamps in series and these groups in multiple, or several lamps in multiple and these groups in series, respectively. They have but a limited application.

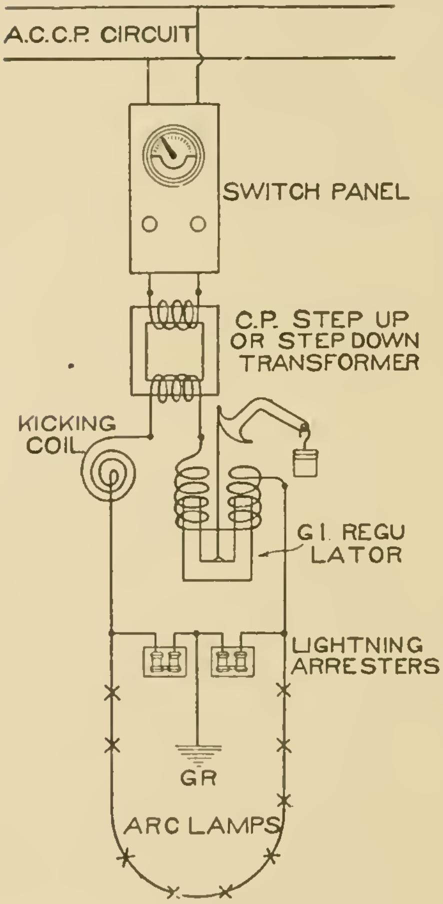


Fig. 32.

Multiple or Parallel Systems of Distribution. By far the largest number of lamps in service are connected to parallel systems of distribution. In this system, the units are connected across the lines leading to the bus bars at the station, or to the secondaries of constant-potential transformers. Fig. 33 shows a diagram of ten lamps connected in parallel. The current delivered by the machine depends directly on the number of lamps connected in service, the voltage of the system being kept constant.

Inasmuch as the flow of current in a conductor is always accompanied by a fall of potential equal to the product of the current flowing, into the resistance of the conductor, the lamps at the end of the system shown will not have as high a voltage impressed upon them as those nearer the machine. This drop in potential is the most serious obstacle that we have to overcome in multiple systems, and various schemes have been adopted to aid in this regulation. The systems may be classified as:

First, Cylindrical Conductors, parallel feeding.
Second, Conical “ “ “
Third, Cylindrical “ anti-parallel feeding.
Fourth, Conical “ “ “

In the cylindrical conductor, parallel-feeding system, the conductors, A, B, C, D, Fig. 33, are of the same size throughout and are fed at the same end by the generator. The voltage is a minimum at the lamps E and a maximum at the lamps F; the value of the voltage at any lamp being readily calculated.

By a conical or tapering conductor is meant a conductor whose diameter is so proportioned throughout its length that the current, divided by the cross-section or the current density, is a constant quantity. Such a conductor is approximated in practice by using smaller sizes of wire as the current in the lines becomes less.

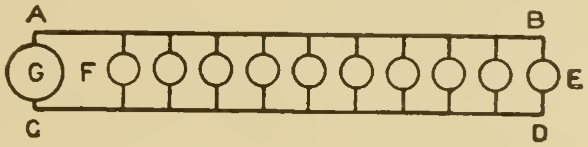


Fig. 33.

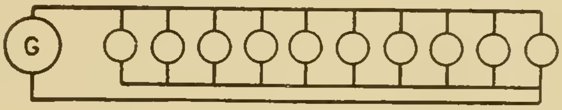


Fig. 34.

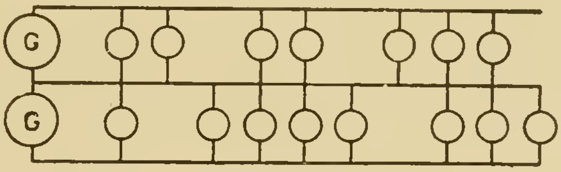


Fig. 35.

In an anti-parallel system, the current is fed to the lamps from opposite ends of the system as shown in Fig. 34.

Multiple-Wire Systems. In order to take advantage of a higher voltage for distribution of power to the lighting circuits, three- and five-wire systems have been introduced, the three-wire system being used to a very large extent. In this system, three conductors are used, the voltage from each outside conductor and the middle neutral conductor being the same as for a simple parallel system. Fig. 35 gives a diagram of this. By this system the amount of copper required for a given number of lamps is from five-sixteenths to three-eighths of the amount required for a two-wire distribution, depending on the size of the neutral conductor. The saving of copper together with the disadvantages of the system is more fully treated in the paper on Power Transmission.

ILLUMINATION.

Illumination may be defined as the quality and quantity of light which aids in the discrimination of outline and the perception of color. Not only the quantity, but the quality of the light, as well as the arrangement of the units, must be considered in a complete study of the subject of illumination.

The Unit of Illumination is the *candle-foot* and its value is the amount of light falling on a surface at a distance of one foot from a source of light one candle-power in value. The law of inverse squares, namely, that the illumination from a given source varies inversely as the square of the distance from the source, shows that the illumination at a distance of two feet from a single candle-power unit is .25 candle-foot. For further consideration of the law of inverse squares, see "Photometry".

Illumination may be classified as *useful* illumination, when used for the ordinary purposes of furnishing light for carrying on work, taking the place of daylight, and *scenic* illumination. The latter applies to all forms of decorative lighting such as stage lighting, etc. The two divisions are not, as a rule, distinct, but the one is combined with the other.

Intrinsic Brightness. By intrinsic brightness is meant the amount of light emitted per unit surface of the light source. Table 3 gives the intrinsic brightness of several light sources.

TABLE 3.

Intrinsic Brilliancies in Candle-Power per Square Inch.

Source	Brilliancy	Notes.
Sun in zenith	600,000	Rough equivalent values, taking account of absorption.
Sun at 30 degrees elev.	500,000	
Sun on horizon	2,000	
Arc light	10,000 to 100,000	Maximum about 200,000 in crater.
Calcium light	5,000	
Nernst "glower"	1,000	Unshaded.
Incandescent lamp	200–300	Depending on efficiency.
Enclosed arc	75–100	Opalescent inner globe.
Acetylene flame	75–100	
Welsbach light	20 to 25	
Kerosene light	4 to 8	Variable.
Candle	3 to 4	
Gas flame	3 to 8	Variable.
Incandescent (frosted)	2 to 5	
Opal shaded lamps, etc.	0.5 to 2	

Regular Reflection. Regular reflection is the term applied to reflection of light when the reflected rays are parallel. It is of such a nature that the image of the light source is seen in the reflection. The reflection from a plane mirror is an example of this. It is useful in lighting in that the direction of light may be changed without complicating calculations aside from deductions necessary to compensate for the small amount of light absorbed.

Irregular Reflection, or diffusion, consists of reflection in which the reflected rays of light are not parallel but take various directions, thus destroying the image of the light source. Rough, unpolished surfaces give such reflection. Smooth, unpolished surfaces generally give a combination of the two kinds of reflection. Diffused reflection is very important in the study of illumination inasmuch as diffused light plays an important part in the lighting of interiors. This form of reflection is seen in many photometer screens. Light is also diffused when passing through semi-transparent shades or screens.

In considering reflected light, we find that, if the surface on which the light falls is colored, the reflected light may be changed in its nature by the absorption of some of the colors. Since, as has been said, in interior lighting the reflected light forms a large part of the source of illumination, this illumination will depend upon the nature and color of the reflecting surfaces.

Whenever light is reflected from a surface, either by direct or diffused reflection, a certain amount of light is absorbed by the surface. Table 4 gives the amount of white light reflected from different materials.

TABLE 4.

Material.	
White blotting paper	.82
White cartridge paper	.80
Chrome yellow paper	.62
Orange paper	.50
Yellow wall paper	.40
Light pink paper	.36
Yellow cardboard	.30
Light blue cardboard	.25
Emerald green paper	.18
Dark brown paper	.13
Vermilion paper	.12
Blue-green paper	.12
Black paper	.05
Black cloth	.012
Black velvet	.004

From this table it is seen that the light-colored papers reflect the light well, but of the darker colors only yellow has a comparatively high coefficient of reflection. Black velvet has the lowest value, but this only holds when the material is free from dust. Rooms with dark walls require a greater amount of illuminating power, as will be seen later.

Useful illumination may be considered under the following heads :

1. Residence Lighting.
2. Lighting of Public Halls, Offices, Drafting Rooms, Shops, etc.
3. Street Lighting.

RESIDENCE LIGHTING.

Type of Lamps. The lamps used for this class of lighting are limited to the less powerful units, namely, incandescent or Nernst lamps varying in candle-power from 8 to 32 per unit. These should always be shaded so as to keep the intrinsic brightness low. The intrinsic brilliancy should seldom exceed 2 to 3 candle-power per square inch, and its reduction is usually accomplished by appropriate shading. Arc lights are so powerful as to be uneconomical for small rooms, while the color of the mercury-vapor light is an additional objection to its use.

Plan of Illumination. Lamps may be selected and so located as to give a brilliant and fairly uniform illumination in a room; but this is an uneconomical scheme, and the one more commonly employed is to furnish a uniform, though comparatively weak, ground illumination, and to reinforce this at points where it is necessary or desirable. The latter plan is satisfactory in almost all cases and the more economical of the two.

While the use of units of different power is to be recommended, where desirable, lights differing in color should not be used for lighting the same room. As an exaggerated case, the use of arc with incandescent lamps might be mentioned. The arcs being so much whiter than the incandescent lamps, the latter appear distinctly yellow when the two are viewed at the same time.

Calculation of Illumination. In determining the value of illumination, not only the candle-power of the units, but the amount of reflected light must be considered for the given location of the lamps. Following is a formula based on the coefficient of reflection of the walls of the room, which serves for preliminary calculations:

$$I = \frac{c.p. \; \frac{1}{1-k}}{d^2}$$

I = Illumination in candle-feet.
$c.p.$ = Candle-power of the unit.
k = Coefficient of reflection of the walls.
d = distance from the unit in feet.

Where several units of the same candle-power are used this formula becomes

$$I = c.p. \left(\frac{1}{d^2} + \frac{1}{d^2_1} + \frac{1}{d^2_2} + \text{----------}\right)\frac{1}{1-k}$$

or,
$$c.p. = \frac{I}{\left(\frac{1}{d^2} + \frac{1}{d^2_1} + \frac{1}{d^2_2} + \text{----------}\right)\frac{1}{1-k}}$$

where d, d_1, d_2, etc., equal the distances from the point considered to the various light sources. If the lamps are of different candle-power, the illumination may be determined by combining the illumination from each source as calculated separately. An example of calculation is given under " Arrangement of Lamps ".

It is readily seen that the effect of reflected light from the ceilings is of more importance than that from the floor of a room. The value of k, in the above formula, will vary from 60% to 10%, but for rooms with a fairly light finish 50% may be taken as a good average value.

The amount of illumination will depend on the use to be made of the room. One candle-foot gives sufficient illumination for easy reading, when measured normal to the page, and probably an illumination of .5 candle-foot on a plane 3 feet from the floor forms a sufficient ground illumination. The illumination from sunlight reflected from white clouds is from 20 candle-feet up, while that due to moonlight is in the neighborhood of .03 candle-foot. It is not possible to produce artificially a light equivalent to daylight on account of the great amount of energy that would be required and the difficulty of obtaining proper diffusion.

Arrangement of Lamps. An arrangement of lamps giving a uniform illumination cannot be well applied to residences on account of the number of units required, and the inartistic effect. We are limited to chandeliers, side lights, or ceiling lights, in the majority of cases, with table or reading lamps for special illumination.

When ceiling lamps are used and the ceilings are high, some form of reflector or reflector lamp is to be recommended. In any case where the coefficient of reflection of the ceilings is less than 40%, it is more economical to use reflectors. When lamps are mounted on chandeliers, the illumination is far from uniform, being a maximum in the neighborhood of the chandelier and a minimum at the corners of the room. By combining chandeliers with side lights it is generally possible to get a satisfactory arrangement of lighting for small or medium-sized rooms.

As a check on the candle-power in lamps required, we have the following:

For brilliant illumination allow one candle-power per two square feet of floor space. In some particular cases, such as ball rooms, this may be increased to one candle-power per square foot.

For general illumination allow one candle-power for four square feet of floor space, and strengthen this illumination with the aid of special lamps as required. The location of lamps and the height of ceilings will modify these figures to some extent.

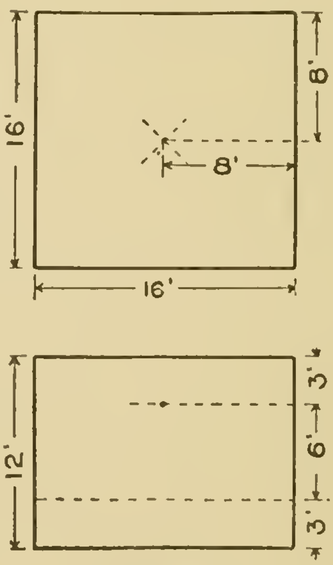


Fig. 36.

As an example of the calculation of the illumination of a room with different arrangements of the units of light, assume a room 16 feet square, 12 feet high, and with walls having a coefficient of reflection of 50%. Consider first the illumination on a plane 3 feet above the floor when lighted by a single group of lights mounted at the center of the room 3 feet below the ceiling. If a minimum value of .5 candle-foot is required at the corner of the room we have the equation

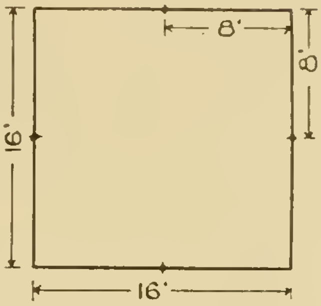
$$.5 = c.p. \frac{1}{12.8^2} \times \frac{1}{1 - .5}$$

Since $d = \sqrt{8^2 + 8^2 + 6^2} = 12.8$ (see Fig. 36)

Solving the above for the value of $c.p.$, we have

$$c.p. = \frac{.5}{\frac{1}{164} \times \frac{1}{.5}} = .5 \times 82 = 41$$

Three 16-candle-power lamps would serve this purpose very well.



Determining the illumination directly under the lamp, we have:

$I = 48 \times \frac{1}{6^2} \times \frac{1}{1 - .5} = \frac{48}{36} \times 2 =$ 2.7 candle-feet, or five times the value of the illumination at the corners of the room.

Next consider four 8-candle-power lamps located on the side walls 8 feet above the floor as shown in Fig. 37. Calculating the illumination at the center of the room on a plane three feet above the floor, we have:

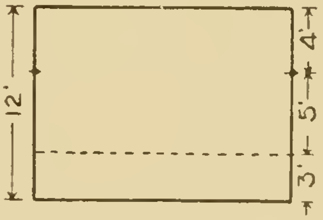


Fig. 37.

$$I = 8\left(\frac{1}{89} + \frac{1}{89} + \frac{1}{89} + \frac{1}{89}\right) \frac{1}{1 - .5}$$

$$d^2 = 8^2 + 5^2 = 64 + 25 = 89$$

$$I = 8 \times \frac{4}{89} \times 2 = .72 \text{ candle-foot.}$$

The illumination at the corner of the room would be:

$$I = 8\left(\frac{1}{89} + \frac{1}{89} + \frac{1}{345} + \frac{1}{345}\right) \frac{1}{1 - .5}$$

$$= 8\left(\frac{2}{89} + \frac{2}{345}\right) \times 2 = .45 \text{ candle-foot.}$$

In a similar manner the illumination may be calculated for any point in the room, or a series of points may be taken and curves plotted showing the distribution of the light, as well as the areas having the same illumination. Where refined calculations are desired, the distribution curve of the lamp must be used for determining the candle-power in different directions. Fig. 38 shows illumination curves for the Meridian lamp manufactured by the General Electric Company. This is a form of reflector lamp made in two sizes, 25 or 50 candle-power. Fig. 39 gives the distribution curves for the 50-candle-power unit. Similar incandescent lamps are now being manufactured by other companies.

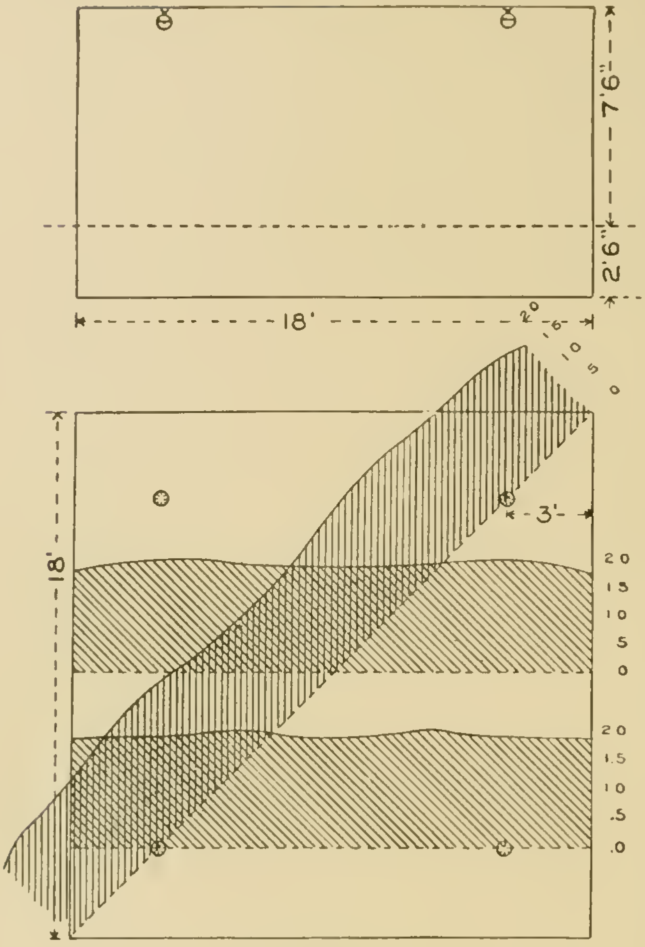


Fig. 38.

Table 5 gives desirable data in connection with the use of the Meridian lamp.

By means of the Weber, or some other form of portable photometer, curves as plotted from calculations may be readily checked after the lamps are installed. When lamps are to be permanently located, the question of illumination becomes an

TABLE 5.

Illuminating Data for Meridian Lamps.

Class Service.	Light Intensity in Candle-feet.	No. 1 Lamp (60 Watts)		No. 2 Lamp (120 Watts)		Watts per Sq. Ft. of Area Lighted With Either Lamp.
		Height of Lamp and Diameter of Uniformly Lighted Area.	Distance Between Lamps When Two or More are Used.	Height of Lamp and Diameter of Uniformly Lighted Area.	Distance Between Lamps When Two or More are Used.	
Desk or Reading Table.	3	2.9 feet.	4.9 feet.	4 feet.	7 feet.	2.50
	2	3 5 "	6 "	5 "	8.5 "	1.66
	1½	4 "	7 "	5.75 "	9.8 "	1.25
General Lighting.	1	5 "	8.5 "	7 "	12 "	0.83
	¾	5.75 "	9.8 "	8.2 "	13.9 "	0.62
	½	7 "	12 "	10 "	11 "	0.41

important one, and it is customary to determine, by calculation, the illumination curves and the isophotals, Fig. 38, as the lines showing equal illumination are called, for each room before installing the lamps. This applies to the lighting of large interiors more particularly than to residence lighting.

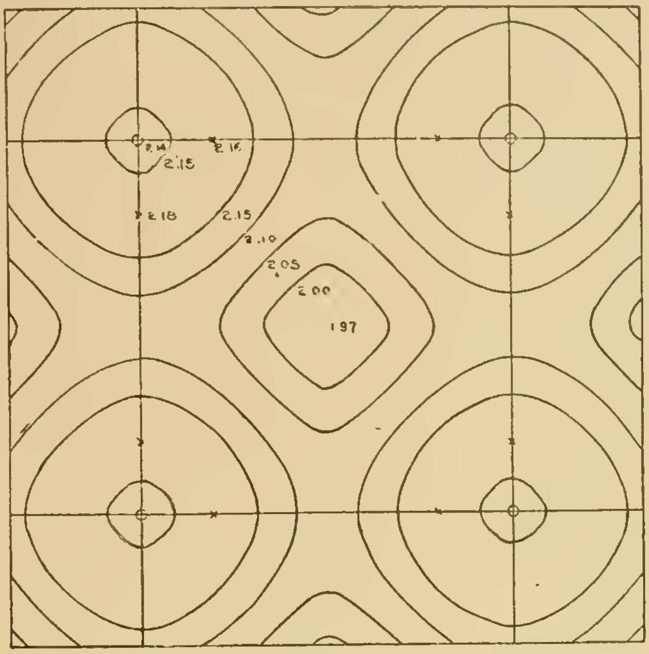


Fig. 38.

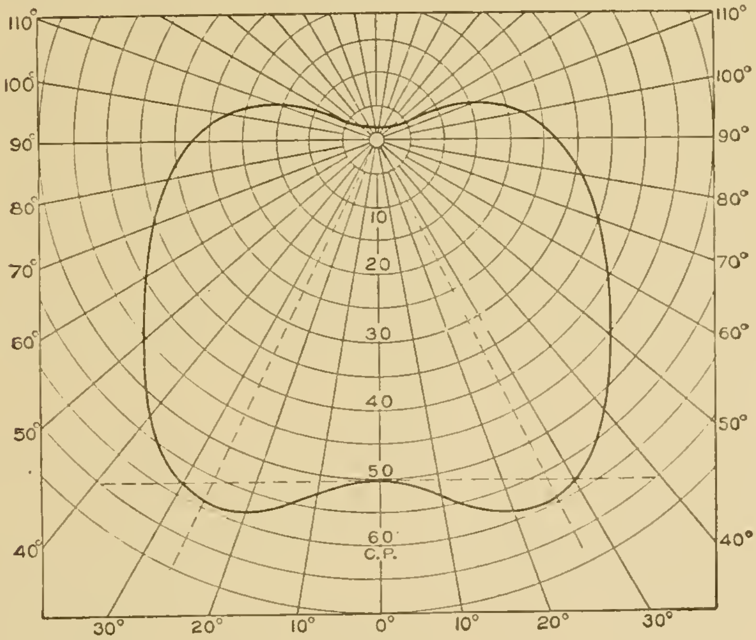


Fig. 39.

Dr. Louis Bell gives the following in connection with residence lighting:

TABLE 6.

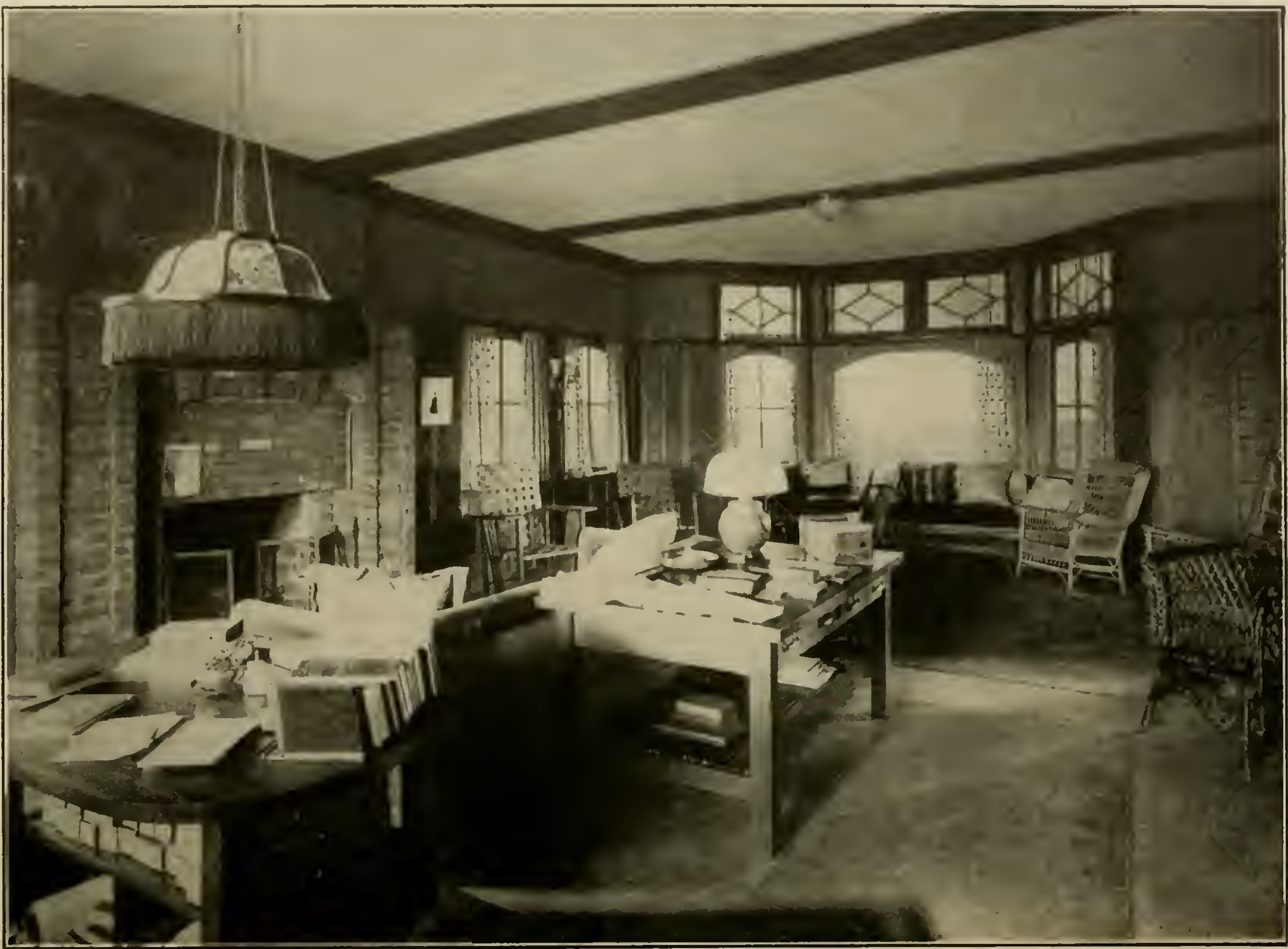
Room.	8 c.p.	16 c.p.	32 c.p.	Sq. ft. per c.p.	Remarks.
Hall, 15′ × 20′	8			4.7	
Library, 20′ × 20′	12		1	3.1	8-c.p. reflector lamps.
Reception room, 15′ × 15′	4			7.0	
Music room, 20′ × 25′	12		2	3.0	
Dining room, 15′ × 20′	14			2.7	8 reflect'r lamps
Billiard room, 15′ × 20′			4	2.3	32-c.p. with reflectors.
Porch			1		
Bedrooms (6), 15′ × 15′		14		7.0	
Dressing rooms (2), 10′ × 15′		4		4.7	
Servants' rooms (3), 10′ × 15′		3		9.4	
Bathrooms (3), 8′ × 10′		3		5.0	
Kitchen, 15′ × 15′ Pantry, 10′ × 15′		3			
Halls Cellar	10	3			
Closets (4)	4				Reflector lamps
Total	64	30	8		

LIGHTING OF PUBLIC HALLS, OFFICES, ETC.

Lighting of public halls and other large interiors differs from the illumination of residences in that there is usually less reflected light, and, again, the distance of the light sources from the plane of illumination is generally greater if an artistic arrangement of the lights is to be brought about. This in turn reduces the direct illumination. The primary object is, however, as in residence lighting, to produce a fairly uniform ground illumination and to superimpose a stronger illumination where necessary. An illlumination of .5 candle-feet for the ground illumination may be taken as a minimum.

In the lighting of large rooms it is permissible to use larger light units, such as arc lamps and high candle-power Nernst or incandescent units, while for factory lighting and drafting rooms, where the color of the light is not so essential, the Cooper Hewitt lamp is being introduced. High candle-power reflector lamps, such as the Meridian lamp, are being used to a large extent for offices and drafting rooms.

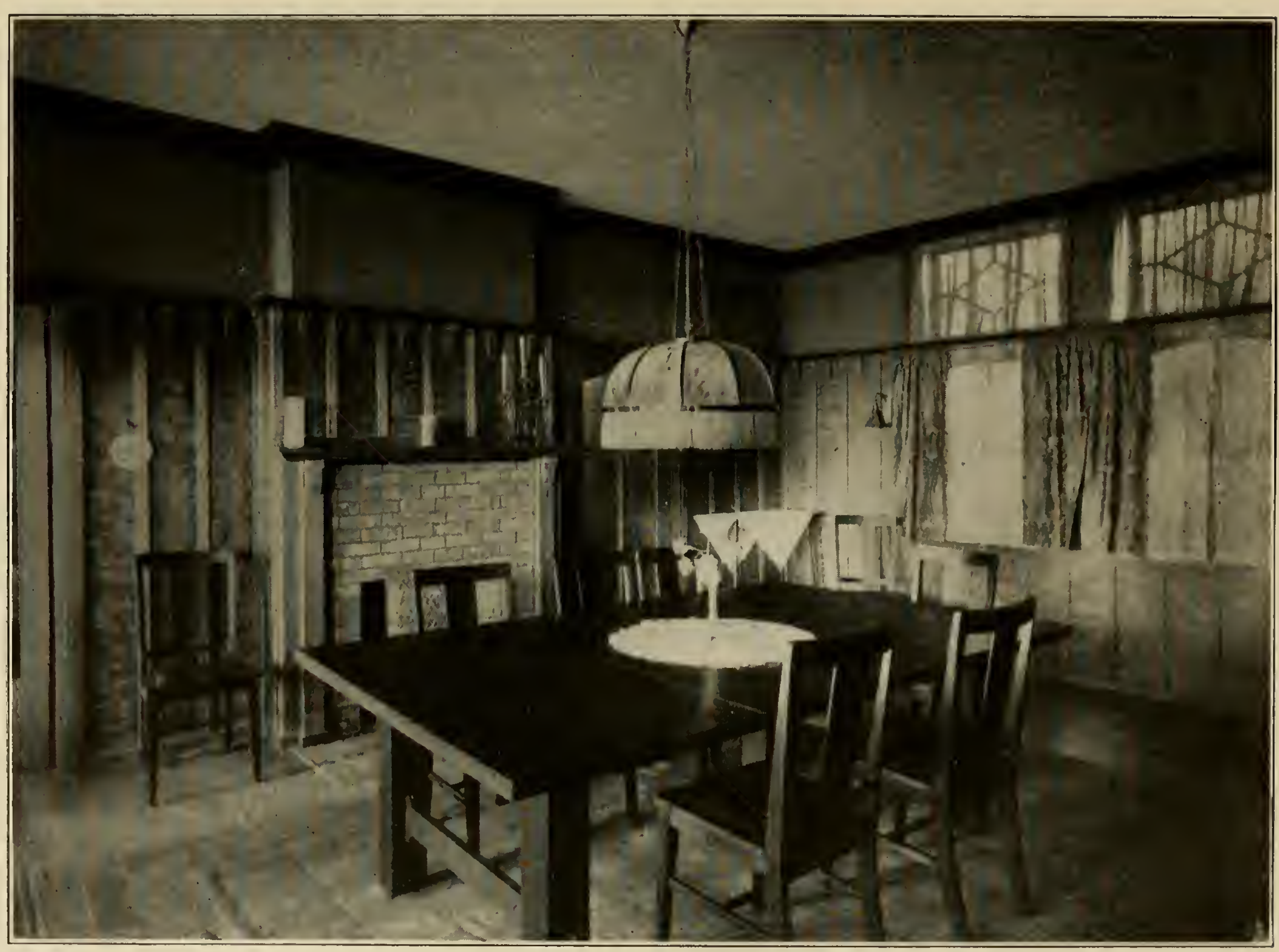
The choice of the type of lamp depends on the nature of the work. Where the light must be steady, incandescent or Nernst



LIVING ROOM IN HOUSE FOR MR. W. F. DUMMER, AT CORONADO BEACH, CAL.

Pond & Pond, Architects, Chicago, Ill.

Selected Curly Redwood Wainscoting; Fireplace, Hard-Burned Variegated Brick. For Plans and Exteriors, See Vol. I, Pages 170 and 186.



DINING ROOM IN HOUSE FOR MR. W. F. DUMMER AT CORONADO BEACH, CAL.
Pond & Pond, Architects, Chicago, Ill.
Curly California Redwood Wainscoting.

lamps are to be preferred to the arc or vapor lamps, though the latter are often the more efficient. When arcs are used, they must be carefully shaded so as to diffuse the light, doing away with the strong shadows due to portions of the lamp mechanism, and to reduce the intrinsic brightness. Such shading will be taken up under the heading "Shades and Reflectors". Arcs are preferable to incandescent lamps when colored objects are to be illuminated, as in stores and display windows.

In locating lamps for this class of lighting, much depends on the nature of the building and on the degree of economy to be observed. For preliminary determination of the location of groups, or the illumination when certain arrangement of the units is assumed, the principles outlined under "Residence Lighting" may be applied. It has been found that actual measurements show results approximating closely such calculated values.

When arcs are used they should be placed fairly high, twenty to twenty-five feet when used for general illumination and the ceilings are high. They should be supplied with reflectors so as to utilize the light ordinarily thrown upwards. When used for drafting-room work, they should be suspended from twelve to fifteen feet above the floor, and special care must be taken to diffuse the light.

Incandescent lamps may be arranged in groups, either as side lights or mounted on chandeliers, or they may be arranged as a frieze running around the room a few feet below the ceiling. The last named arrangement of lights is one that may be made artistic, but it is uneconomical and when used should serve for the ground illumination only. Reflector lights may be used for this style of work and the lights may be entirely concealed from view, the reflecting property of the walls being utilized for distributing the light where needed.

Ceiling lights should preferably be supplied with reflectors, especially when the ceilings are high.

Measurements taken in well-lighted rooms having a floor space of from 1,000 to 5,000 square feet show an average of 3 to 3.5 square feet per candle-power. About 2.5 square feet per candle-power should be allowed when brilliant lighting is required or the ceilings are very high, while 3.75 square feet per candle power

TABLE 7.

Lighting Data for Arc Lamps.

Place Lighted.	Clothing Store	Weave Room.	Erecting Room.	Machine Shop.	Drafting Room.	Drafting Room.	Ship Shed.	Cataloging Dept.	Jewelry Store.
No. of sq. ft. place lighted...	4000	14100	281600	42250	6275	5690	69000	4136	4000
No. lamps used..............	12	50	200	42	27	24	50	17	6
Circuit......................	A. C. Mult	D. C. Mult.	D. C. Mult.	D. C. Mult.	A. C. Series.	D. C. Mult.	*D. C. Mult.	D. C. Mult.	D. C. Mult.
Cycles......................	60	......	......	......	60	......	......	......	......
Volts line..................	104	110	120	120	......	120	220	110	110
Amperes....................	6	3¼	6.2	6.2	7.5	4	6	4½	5
Volts at arc................	72	75	80	80	72	80	80	80	80
Power factor of lamp........	.69	......	......	......	.86	......	......	......	......
Watts per lamp..............	430	357	744	744	490	480	660	495	550
Watts per sq. ft. (term.).....	1.29	1.24	.53	.74	2.11	2.02	.478	2.03	.825
Kw. at term. (whole installation)	5.16	17.8	148.8	31.25	13.22	11.52	33	8.42	3.3
Kw. at arc (whole installation)	4.62	12.28	99.2	20.8	12.42	7.68	24	6.12	2.4
Sq. ft. lighted per lamp......	333	288	1408	1006	232	237	1380	243	667
Sq. ft. lighted per amp.......	55.6	88.6	227	162	34	59.2	230	54.1	133.5
Enclosing globe.............	Opal		Opal.	Opal.	Opal.	Opal.		Opal.	Opal.
Height and style of ceiling..	12′ white steel.	Saw Toothed.	Trussed.	Trussed.	12′ White.	Trussed.	160′ Trussed.	13′ 9″ Maroon.	16′ 10′ White.
Reflector system used.......	Concentric Diffuser.	Adjust. Diffuser.	9″ Mirror.	9″ Mirror.	Concentric Diffuser.	16 Adj. Dif. 8 Con. Dif.	12″ Mirror.	Concentric Diffuser.	Concentric Diffuser.
Height of arc from floor.....	9′ 6″	12′ to 15′	46′	47′	9′	15′	150′	10′ 7″	13′ 2″
Distance between lamps.....	14′ to 18′	24′	32′ to 38′	30′ 9″	15′	12′ to 25′	17′ to 20′	14′ to 18′	16′ to 25′

will give good illumination when lights are well distributed and there is considerable reflected light.

In factory and drafting room lighting, the lamps must be arranged to give a strong light where most needed, and located to prevent such shadows as would interfere with the work.

Following are tables showing the number and distribution of arc and mercury-vapor lamps for lighting large rooms. Table 7 refers to arc lights as actually installed.

TABLE 8.

Lighting Data for Cooper-Hewitt Lamps.

Drafting Room.	2,140 sq. ft.	8 Y-5 lamps.
	265 sq. ft. per lamp.	8 × 3.3 amperes = 26.5 amp.
	voltage 110.	80 sq. ft. per amp.
Office.	1,100 sq. ft.	3 H-4 lamps.
	366 sq. ft. per lamp.	3x3.3 amp. = 10 amp.
	voltage 110.	110 sq. ft. per amp.
Factory.	12,000 sq. ft.	30 Y-4 lamps.
	400 sq. ft. per lamp.	30x1.7 amp. = 51 amp.
	voltage 110.	

STREET LIGHTING.

In studying the lighting of streets and parks, we find that, except in special cases, such as narrow streets and high buildings, there is no reflected light which aids the illumination aside from that due to special shades or reflectors on the lamp itself. Such reflectors are necessary if the light ordinarily thrown above the horizontal plane is to be utilized.

In calculating the illumination due to any type of lamp at a given point it is necessary to know the distribution curve of the lamp used and the distance to the point illuminated. The approximate illumination is given by the formula,

$$I = \frac{c.p.}{h^2 + d^2}$$

when I = illumination in candle-feet.

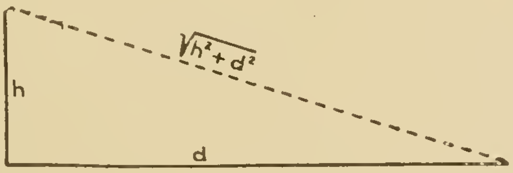


Fig. 40.

c.p. = candle-power of the unit, determined from the distribution curve of the lamp.

h = distance the lamp is mounted above the ground, in feet, and d = distance from the base of the pole supporting the lamp to the point where the illumination is being considered. See Fig. 40.

While this will give the illumination in candle-feet, the nature of the lighting cannot be decided from this alone, but the total amount of light must also be considered. Thus, a street lighted with powerful units and giving a minimum illumination of .05 candle-foot would be considered better illuminated than one having smaller units so distributed as to give the same minimum value.

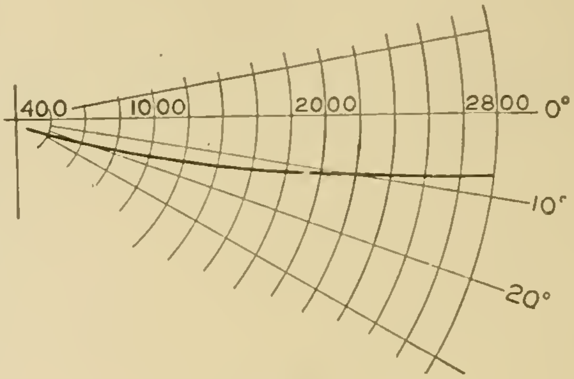


Fig. 41.

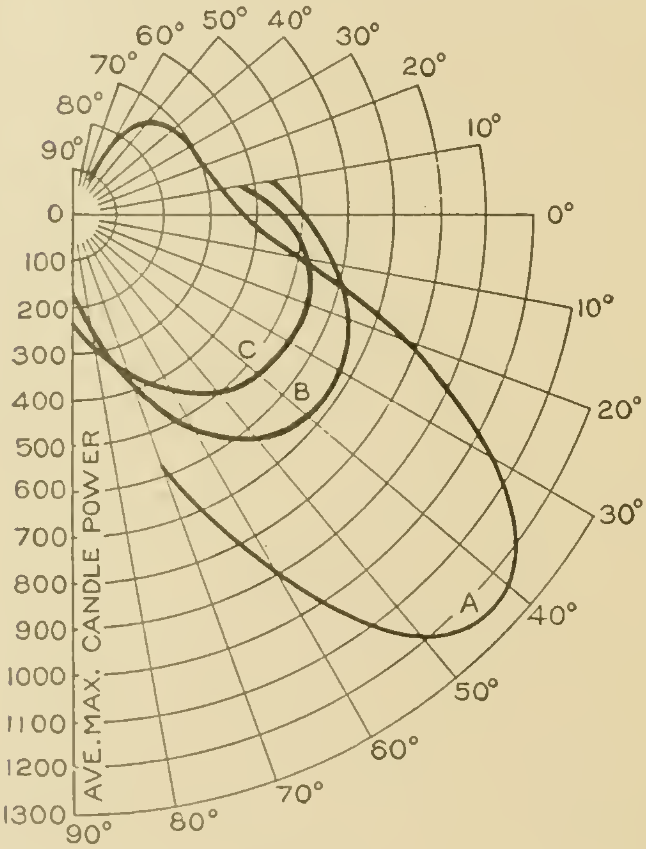


Fig. 42.

Since a uniform distribution of light is desirable, for economic reasons, the ideal distribution curve of a lamp for street lighting would be a curve which shows a low value of candle-power thrown directly downward, but with the candle-power increasing as we approach the horizontal. Such an ideal distribution curve is shown in Fig. 41.

Actual distribution curves taken from commercial arc lamps are given in Fig. 42, in which

Curve A shows distribution curve for a 9.6-ampere, open, direct-current arc.

Curve B shows distribution curve for a 6.6 ampere, D.C. enclosed arc.

Curve C shows distribution curve for a 7.5-ampere, A.C. enclosed arc.
Globes used with B and C are opal, inner globes, clear, outer globes.
Globes used with A are clear outer globes.
A street reflector was used with the enclosed arcs.

A series of curves known as illumination curves may be readily calculated showing the illumination in candle-feet at given distance from the foot of the pole supporting the lamp. Illumination curves corresponding to the distribution curves in Fig. 42 are given in Fig. 43 where A′, B′, and C′ correspond to A, B, and

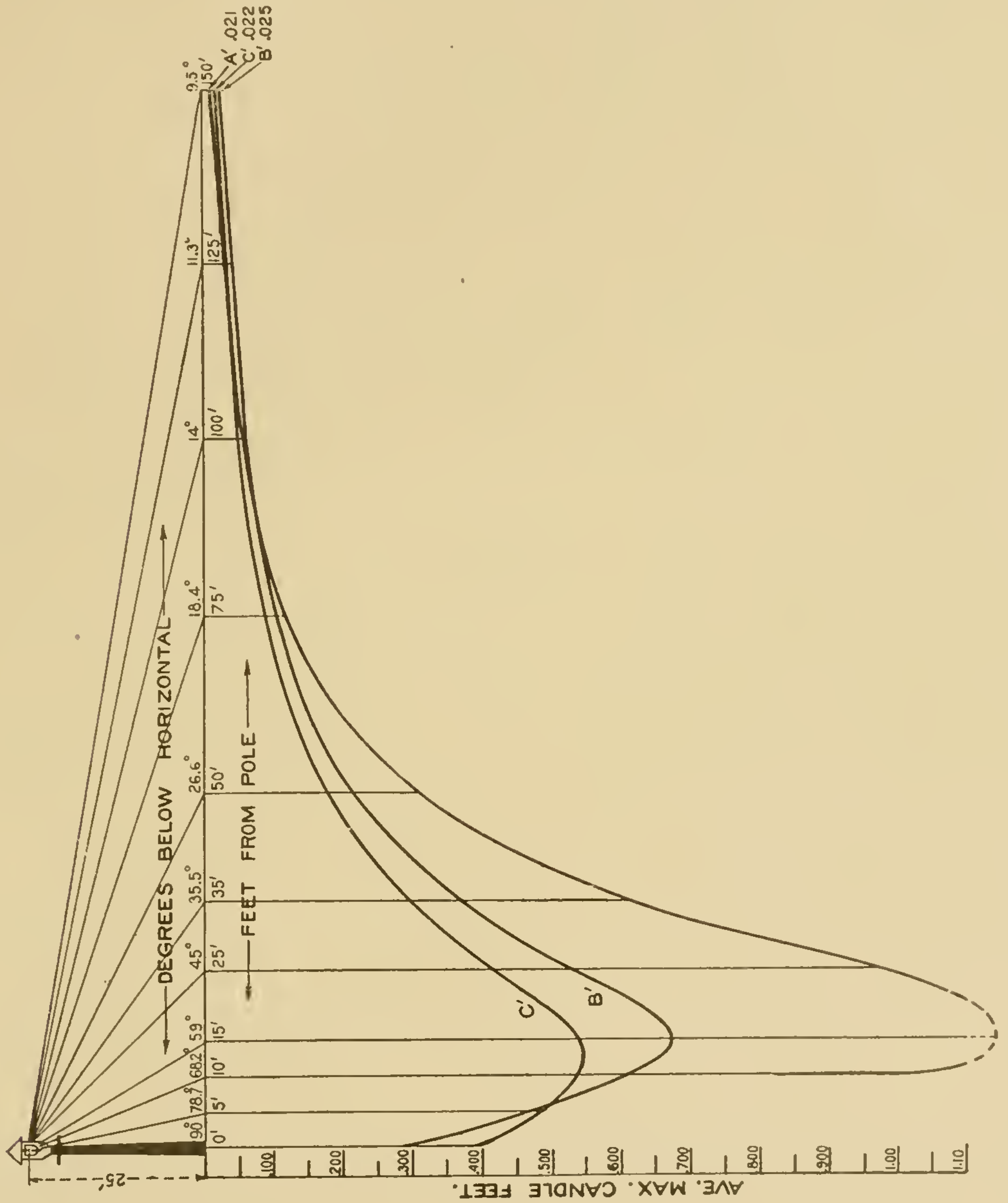


Fig. 43.

C in Fig. 42. These curves correspond to actual readings taken with commercial lamps. Similar curves for incandescent lamps are shown in Fig. 44. A value of .03 candle-foot is about the minimum for good street lighting. Open arcs should be placed at least 25 feet above the ground; 30 to 40 feet is better, especially if the space to be illuminated is quite open. With enclosed arcs it is often advantageous to place them as low as 18 to 20 feet from the ground. Table 9 gives the distance between lights for different types of arcs for good illumination.

TABLE 9.

Kind of Light.	Distance between Lights.	Lights Per Mile.
6.6-ampere enclosed D.C. arc............	340 Feet.	15
9.6-ampere open D.C. arc................	315 "	17
6.6-ampere enclosed A.C. arc............	275 "	19
6.6-ampere open D.C. arc................	260 "	20

In considering the type of arc light to be used we must turn to the illumination curves as shown in Fig. 43. These curves show that the illumination from a direct-current open arc in its present form is superior to that from a direct-current enclosed arc, taking the same amount of power, in the vicinity of the pole, but at a distance of 100 feet, the illumination from the enclosed arc is better. This illumination is still more effective on account of the absence of such strong light as is given by the open arc near the pole. The pupil of the eye adjusts itself to correspond to the brightest light in the field of vision, and we are unable to see as well in the dimly-lighted section as when the maximum intensity is less. The characteristics of the open, direct-current arc lamps are as follows:

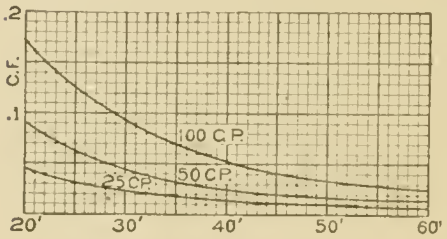


Fig. 44.

The mean spherical candle-power and energy required at the arc are variable.

Fluctuations of light are marked, due to wandering of the arc, flickering due to the wind and lack of uniformity of the carbons.

Dense shadows are cast by the side rods and the lower carbon, while the light is objectionably strong in the vicinity of the pole.

With the enclosed arc the mean spherical candle-power and the watts consumed at the arc are fairly constant.

No shadows are cast by the lamps, and the illumination is not subject to such wide variations. The enclosed arc is much superior to the open arc using the same amount of energy. This applies to the open arc as it is now used. With proper reflection and diffusion of the light such as might be accomplished by extensive or special shading, we ought to be able to get as good distribution from the open arc with a greater total amount of illumination.

In comparing the direct-current with the alternating-current enclosed arc, we see that the direct-current arc gives slightly more light than the alternating lamp, but this may be more than counterbalanced by the better distribution of light from the alternating-current lamp. The selection of A.C. or D.C. enclosed lamps will usually depend on other conditions, such as method of distribution of power, efficiency of plant, etc.

Series incandescent lamps are used considerably for lighting the streets in residence sections of cities or where shade trees make it impracticable to use arcs. These vary in candle-power from 16 to 50 or even higher, and are usually constructed so as to take from two to four amperes. The best arrangement of these is to mount them on brackets a few feet from the curb, with alternate lamps on opposite sides of the street. The distance between the lamps depends on their power. 50 candle-power lamps spaced 100 feet between lamps, give a minimum illumination of .02 candle-foot. 25 candle-power lamps spaced 75 feet between lamps will serve where economy is necessary.

SHADES AND REFLECTORS.

Lamps, as ordinarily constructed, do not always give a suitable distribution of light, while the intrinsic brightness is often too high for interior lighting. Shades are intended to modify the intensity of the light, while reflectors are used for the purpose of changing its direction. Frequently the two are combined in various ways. Shades are also used for decorative purposes, but, if possible, these should be of such a nature as to aid illumination rather than to reduce its efficiency.

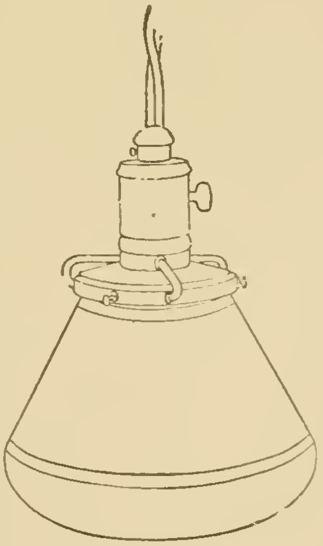


Fig. 45.

A considerable amount of light is absorbed by the material used for the construction of shades. Table 10 shows the approximate amount absorbed by some materials.

Of the great number of styles of shades and reflectors in use, only a few of the more important will be considered here.

TABLE 10.

	Per Cent
Clear glass	10
Alabaster glass	15
Opaline glass	20–40
Ground glass	25–30
Opal glass	25–60
Milky glass	30–60
Ground glass	24.4
Prismatic glass	20.7
Opal glass	32.2
Opaline glass	23.0

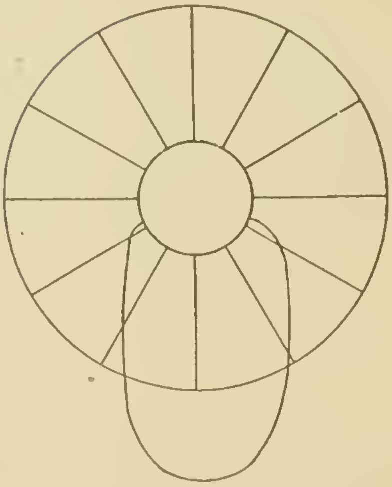


Fig. 46.

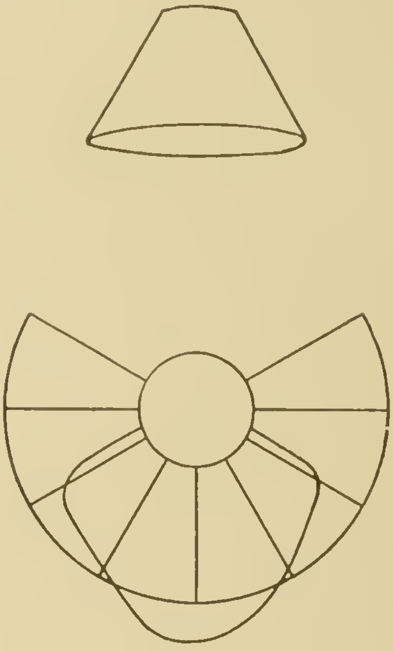


Fig. 47.

One of the simplest methods of shading incandescent lamps is by the use of "frosted" globes. These serve to reduce the intrinsic brightness of the lamp, and should be freely used for residence lighting when separate shades are not installed. Frosted globes are also used in connection with reflectors for the purpose of diffusing the reflected light. The McCreary shade as shown in

Fig. 45 is an example of such a combined shade and reflector. Fig. 46 shows the distribution curve taken from an incandescent lamp using a McCreary shade. Fig. 47 shows the distribution of light from a conical shade. Fig. 39 shows the distribution of light brought about by means of a spiral filament and a reflector as used in the Meridian lamp.

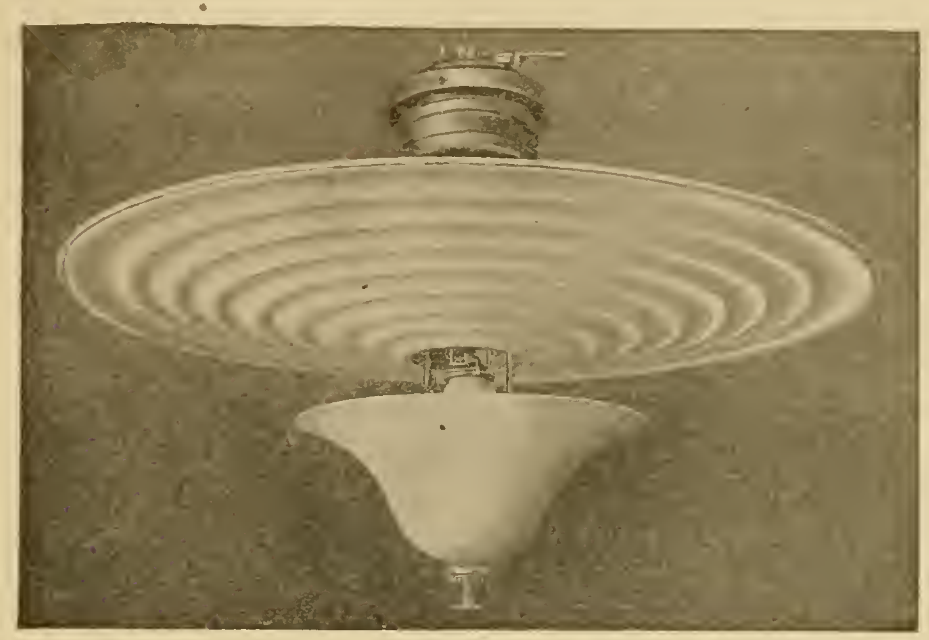


Fig. 48.

Holophane globes are made for both reflecting and diffusing the light, and they can be made to bring about almost any desired distribution with but a small amount of absorption of light. These consist of shades of clear glass having horizontal grooves forming surfaces which change the direction of light by refraction or total reflection as is necessary. The diffusion of light is effected by means of deep, rounded, vertical grooves on the interior surface of the globe. While these globes are of clear glass and absorb an amount of light corresponding to clear glass, the light is so well diffused that the filament of the lamp cannot be seen, and the globe appears as if made of some semi-transparent material. The objections to globes of this type are their high cost and the difficulty in keeping them clean.

Fig. 48 shows an enclosed arc lamp fitted with a concentric "diffuser." This shade is sometimes applied to an inverted arc, which is a direct-current arc in which the lower carbon is made positive. The effect of this combination is best shown in Fig. 49. Fig. 50 shows the change in the illumination curve produced by such shading. Inverted arcs have a considerable application when the light may be readily reflected and diffused as in lighting large rooms with light finish.

Fig. 51 shows another form of adjustable diffuser which finds application when a soft light is required for a definite direction. This shade is very readily adapted to shop lighting.

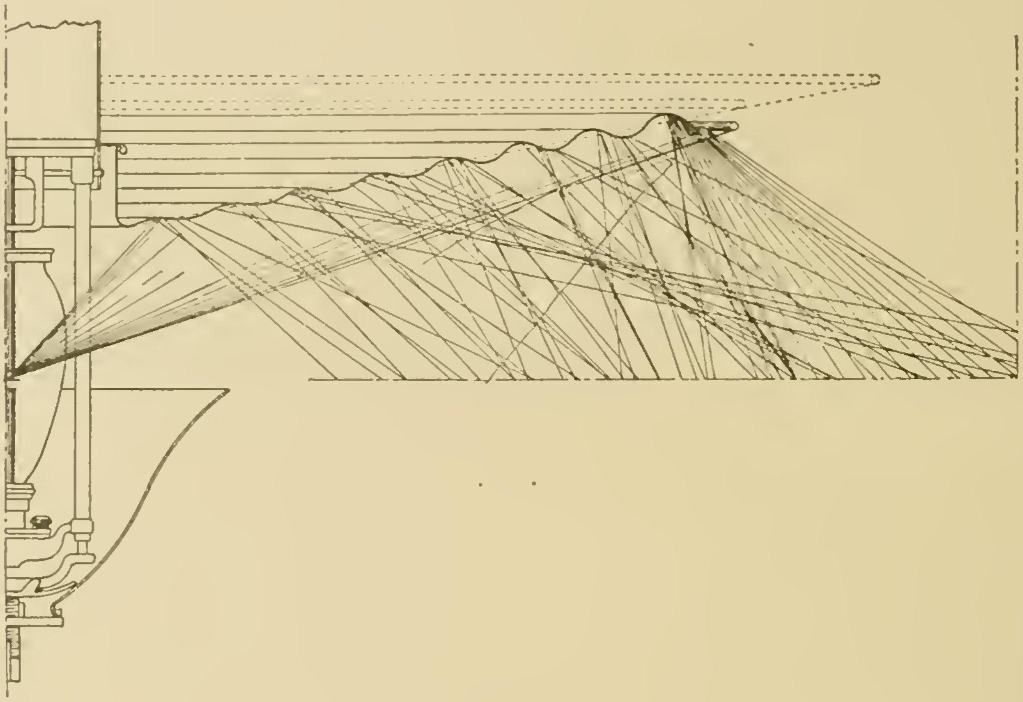


Fig. 49.

The use of opal enclosing globes is recommended for arc lamps used for street lighting for the reason that they change the distribution of the light so that it covers a greater area, and the light is so diffused as to obliterate shadows in the vicinity of the lamp. Table 11 gives the efficiency of different globe combinations for street lighting assuming the opal inner and the clear outer globes as 100%.

TABLE 11.

Opal	enclosing	and	clear	outer	100	per cent.
Clear	"	"	clear	"	91.2	"
"	"	"	opal	"	85.1	"
Opal	"	"	opal	"	82.7	"

PHOTOMETRY.

Photometry is the art of comparing the illuminating properties of light sources, and forms one branch of scientific measurement. Its use in electric illumination is to determine the relative values of different types of lamps as sources of illumination, together with their efficiency ; also by means of the principles of photometry, we are able to study the distribution of illumination for any given arrangement of light sources.

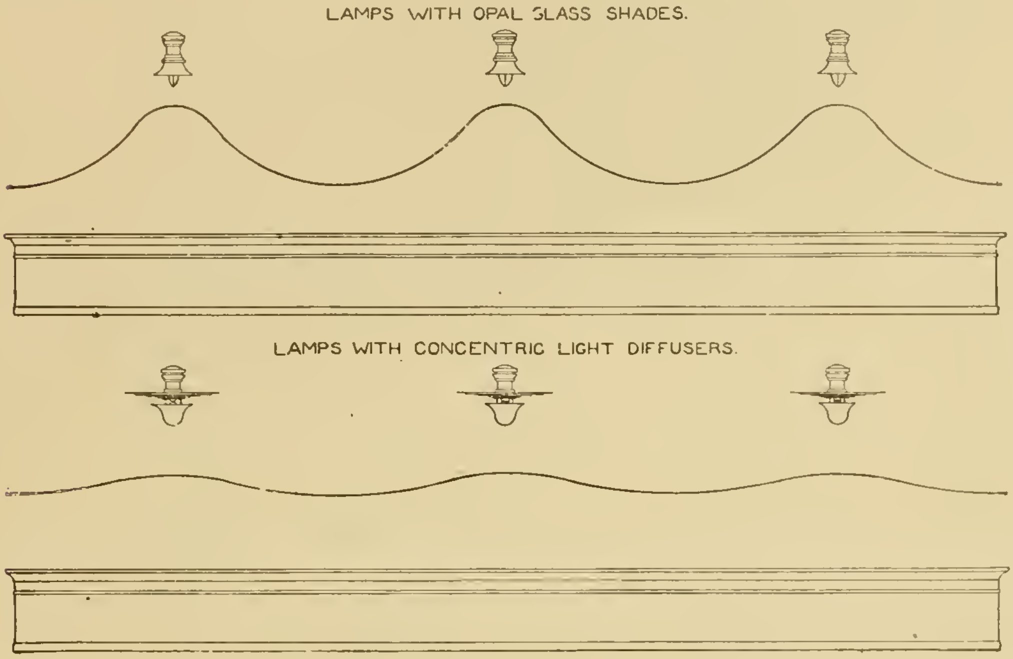

LAMPS WITH OPAL GLASS SHADES.
LAMPS WITH CONCENTRIC LIGHT DIFFUSERS.

Fig. 50.

Light Standards. Inasmuch as sources of light are compared with one another in photometry, we must have some standard, or unit, to which all light sources are reduced. This unit is usually the candle-power and the rating of most lamps is given in candle-power.

While the candle-power remains the unit and is based on the standard English candle, other light standards have been introduced and are much more desirable.

The English Candle. The English candle is made of spermaceti extracted from crude sperm oil, with the addition of a small quantity of beeswax to reduce the brittleness. Its length is ten inches, and its diameter .9 inch at the bottom and .8 inch at the top, and its weight is one-sixth of a pound. Great care is taken in the preparation of the wick and spermaceti. This candle burns with a normal height of flame of 45 millimeters and consumes 120 grains per hour when burning in dry air at normal atmospheric pressure. Under these conditions, the light given by a single candle is one candle-power.

When used for measurements, the candle should be allowed to burn at least fifteen minutes before taking any readings. At the end of this period the wick should be trimmed, if necessary, and when the flame height reaches 45 millimeters, readings can be taken. The candle should not require trimming when the proper height of flame has been reached. It is best to weigh the amount of material consumed by balancing the candle on a properly arranged balance when the first reading is taken, and again balancing at the end of a suitable period—ten to fifteen minutes. The candle-power of the unit is then, practically, directly proportional to the amount of the material consumed.

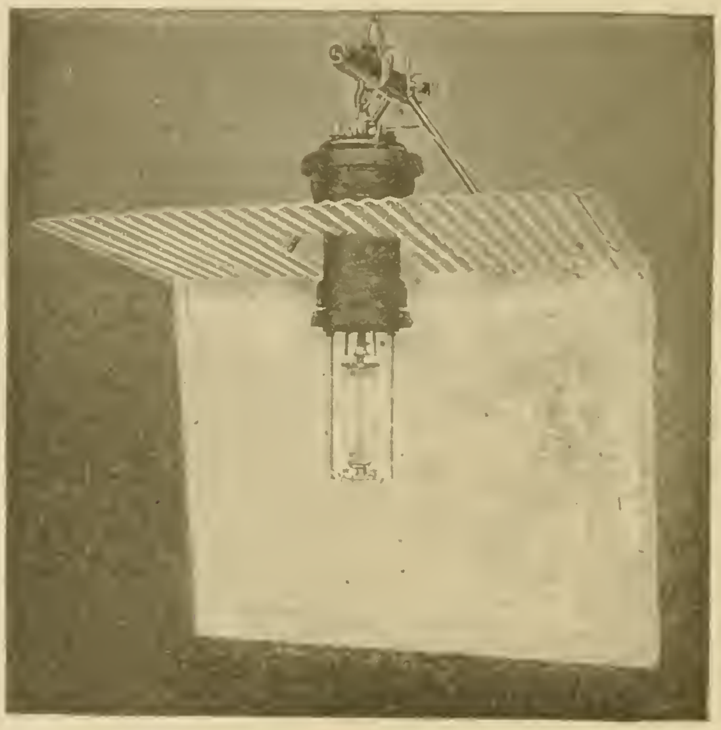


Fig. 51.

The objections to the candle as a unit are that it burns with an open flame which is subject to variation in height and to the effect of air currents. The color of the light is not satisfactory, being too rich in the red rays and the composition of the spermaceti is more or less uncertain.

The German Candle is made of paraffine, very pure, and burns with a normal flame height of 50 millimeters and is subject to the same disadvantages as the English candle. It may be necessary to trim the wick to keep the flame height at 50 millimeters. The light given is a trifle greater than for the spermaceti candle.

The Carcel Lamp is built according to very careful specifications and burns colza (rape seed) oil. It has been used to a large extent in France, but its present application is limited.

The Pentane Lamp is a specially constructed lamp burning pentane, prepared by the distillation of gasoline between narrow limits of temperature. This standard is not extensively used.

The Amyl Acetate Lamp. This lamp, known also as the Hefner lamp, is at present the most desirable standard. It is a lamp built to very careful specifications, especially with regard to the dimension of the wick tube. It burns pure amyl acetate and the flame height should be 40 millimeters. This flame height must be very carefully adjusted by means of gauges furnished with the lamp. Amyl acetate is a colorless hydrocarbon prepared from the distillation of amyl alcohol obtained from fusil oil, with a mixture of acetic and sulphuric acids, or by distillation of a mixture of amyl acetate, sulphuric acid, and potassium acetate. It has a definite composition, and must be pure for this use.

The most serious disadvantage of this standard is the color of the light, inasmuch as it has a decidedly red tinge and is not readily compared with whiter lights. Its value is affected somewhat by the moisture in the air and the atmospheric pressure, but it excels all other standards in that it is quite readily reproduced.

Below is given the accepted value of the English and German candle in terms of the Hefner unit.

The Paraffine Candle (Vereinskerze) at a flame height of 50 millimeters. = 1.2 Hefner Units.

The English candle at a flame height of 45 millimeters.... = 1.14 Hefner Units.

Working Standards. The units just described, together with some others, form reference standards, but an incandescent lamp is generally used as the working standard in all photometers. An incandescent lamp, when used for this work, should be burned for about two hundred hours, or until it has reached the point in the life curve where its value is constant, and it should then be checked by means of some standard when in a given position and at a fixed voltage. It then serves as an admirable working standard if the applied voltage is carefully regulated. Two such lamps should always be used—the one to serve as a check on the other; the checking lamp to be used for very short intervals only.

Photometers. Two light sources are compared by means of a photometer which, in one of its simplest forms, consists of what is known as a Bunsen screen mounted on a carriage between the two lights being compared, with its plane at right angles to a line passing through the light sources, and arranged with mirrors or prisms so that both sides of the screen may be observed at once. The Bunsen screen consists of a disc of paper with a portion of either the center, or a section around the center, treated with paraffine so as to render it translucent. If the light falling on one side of this screen is in excess, the translucent spot will appear dark on that side of the screen and light on the opposite side. Care must be taken to see that the two sides of the screen are exactly alike, otherwise there will be an error introduced in using the screens. It is well to reverse the screen and check readings whenever a new lot of lamps are to be tested. When the light falling on the two sides of the screen is the same, the transparent spot disappears. The values of the two light sources are then directly proportional to the square of their distances from the screen. As an example, consider a 16 candle-power lamp being compared with a standard candle. Say the translucent spot disappears when the screen is distant 60 centimeters from the standard candle, we then have the proportion,

$$x : 1 = (240)^2 : (60)^2 = 16 : 1,$$

showing that the lamp gives 16 candle-power.

The above law is known as the law of inverse squares, and holds true only when the dimensions of the light sources are small compared with the distance between them, and when there are no reflecting surfaces present as when the readings are taken in a dark room.

The proof that the light varies inversely with the square of distance from the source is as follows:

Consider two spherical surfaces, Fig. 52, illuminated by a source of light at the center. The same quantity of light falls on both surfaces.

$$\text{Area of } S = 4\pi R^2 \text{ sq. ft. (R is in feet.)}$$

$$\text{Area of } S_1 = 4\pi R^2_1 \text{ sq. ft.}$$

Let Q = total quantity of light and q = light falling on unit surface. Then,

$$q = \frac{Q}{4\pi R^2}$$

$$q_1 = \frac{Q}{4\pi R^2_1}$$

$$q : q_1 = \frac{Q}{4\pi R^2} : \frac{Q}{4\pi R^2_1}$$

$$= 4\pi R^2_1 : 4\pi R^2$$

$$\frac{q}{q_1} = \frac{R^2_1}{R^2}$$

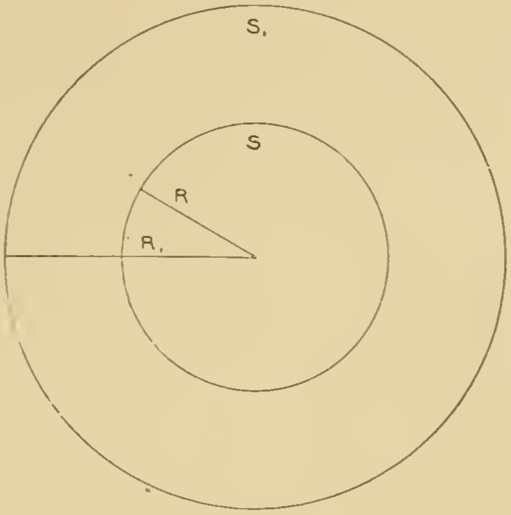


Fig. 52.

Fig. 53 shows the relation in another way. The area of C, distant two units from the source of light A, is four times that of B which is distant one unit.

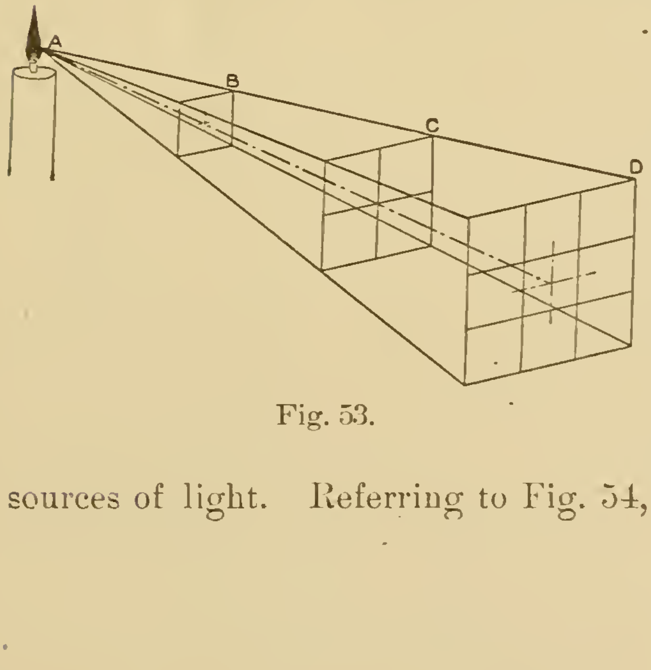


Fig. 53.

The Lummer-Brodhun Photometer. In addition to the Bunsen Screen described, there are several other forms of photometers, the most important of which is the Lummer-Brodhun. The essential feature of this instrument is the optical train which serves to bring into contrast the portions of the screen illuminated by the two sources of light. Referring to Fig. 54, the screen S is an opaque screen which reflects the light falling upon it from L. to the mirror M, when it is again reflected to the pair of glass prisms A, B. The surfaces *sr* are ground to fit perfectly and any light falling on this surface will pass through the prisms. Light falling on the surface *ar* or *bs* will be reflected as shown by the arrows. We see then that the light from L, which falls on *ar* and *bs*, is reflected to the eye piece or telescope T, while that falling on *sr* is transmitted to and absorbed by the black interior of the containing box. Likewise, the light from the screen L_1 is reflected by the screen M_1 to the pair of prisms A, B. The rays falling on the surface *sr* pass through to the telescope T, while the rays falling on *ar* and *bs* are reflected and absorbed by the black lining of the case. The field of light, as then viewed through the telescope, appears as a disc of light produced by the screen L_1, surrounded by an annular ring of light produced by L. When the illumination on the two sides of the screen is the same, the disc and ring appear alike and the dividing circle disappears.

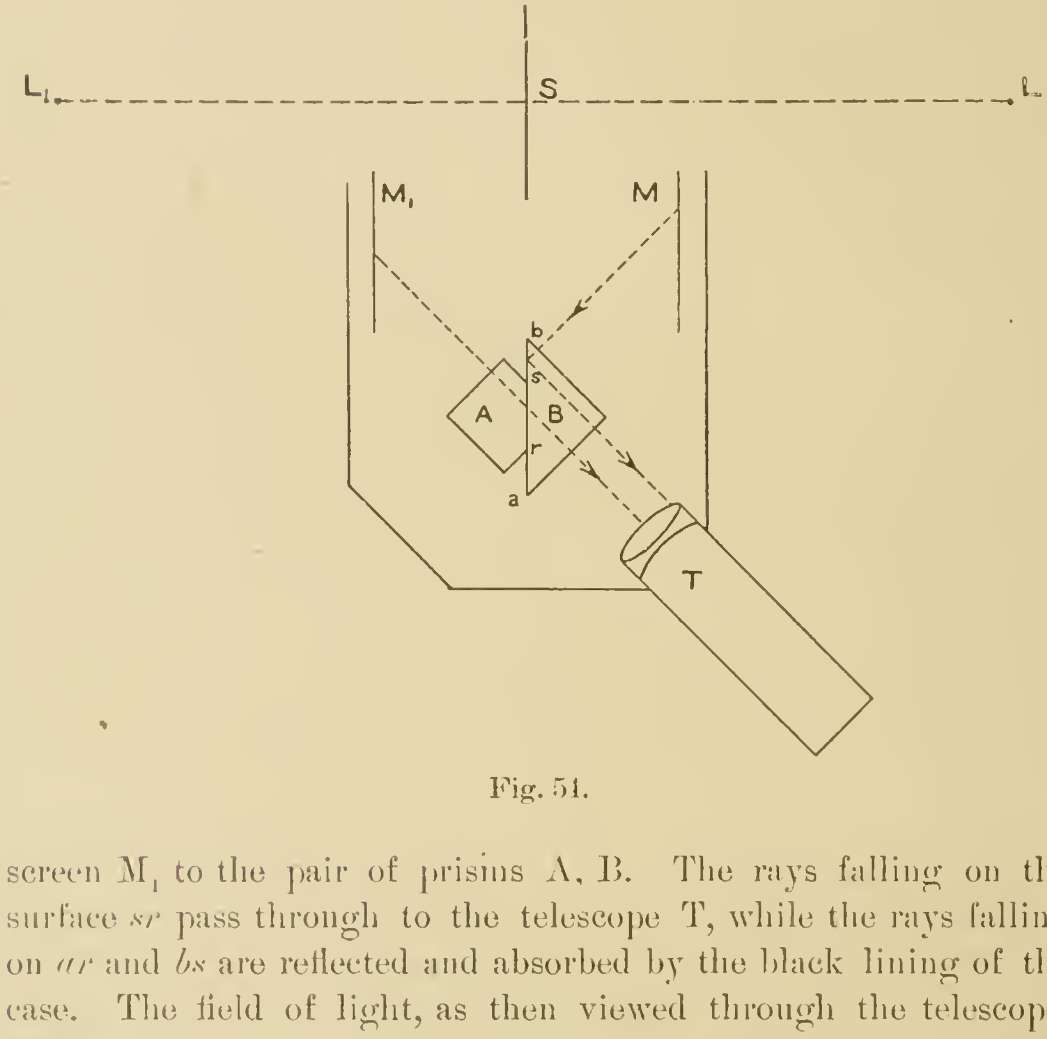
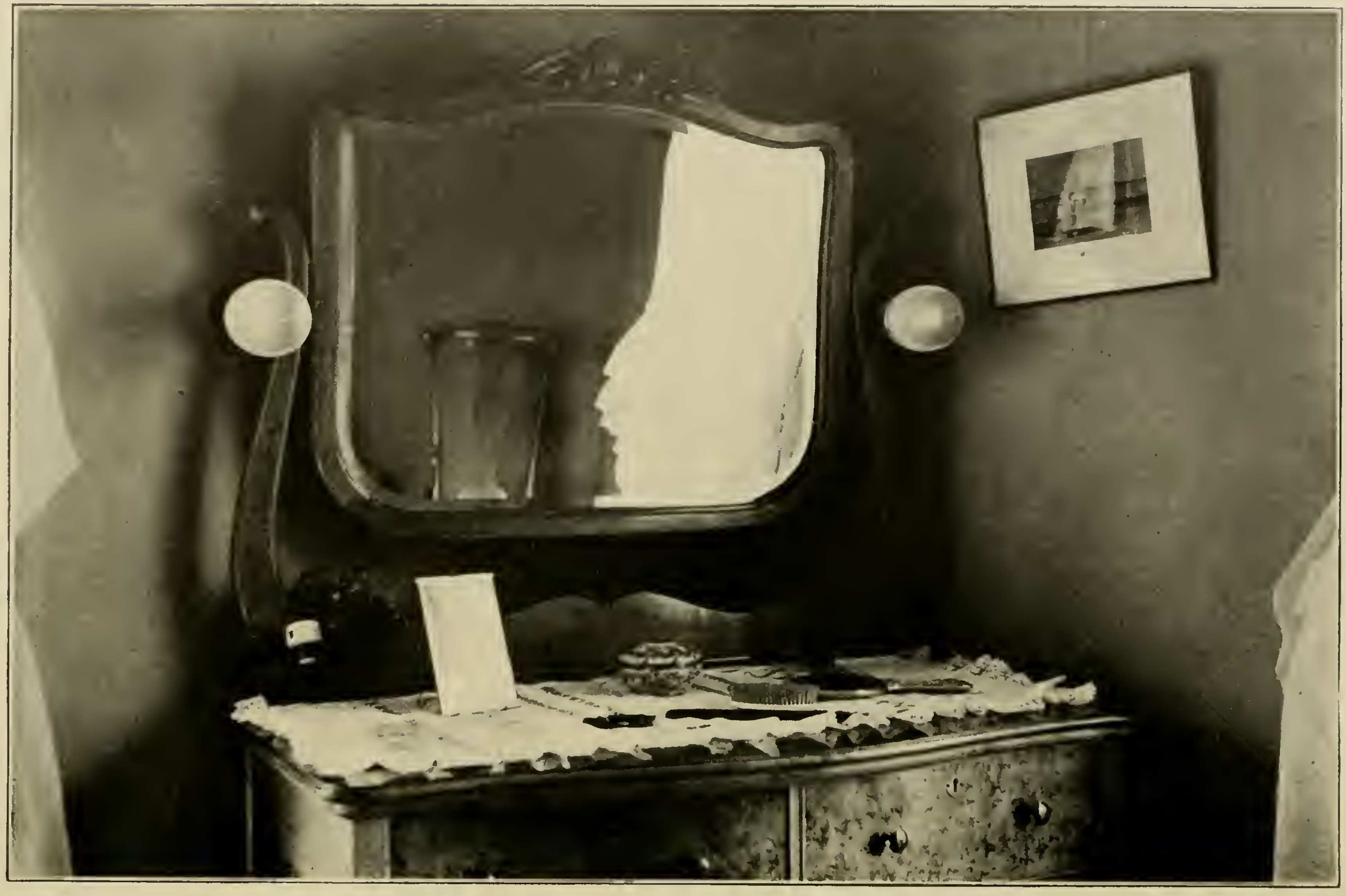


Fig. 51.

In using this screen, it is mounted the same as the Bunsen screen and readings are taken in the same manner. The screen



GOOD METHOD OF LIGHTING UP A DRESSER.

and prisms are arranged so that they can be reversed readily and two readings should always be taken to compensate for any inequalities in the sides of the screen and the reflecting surfaces, a

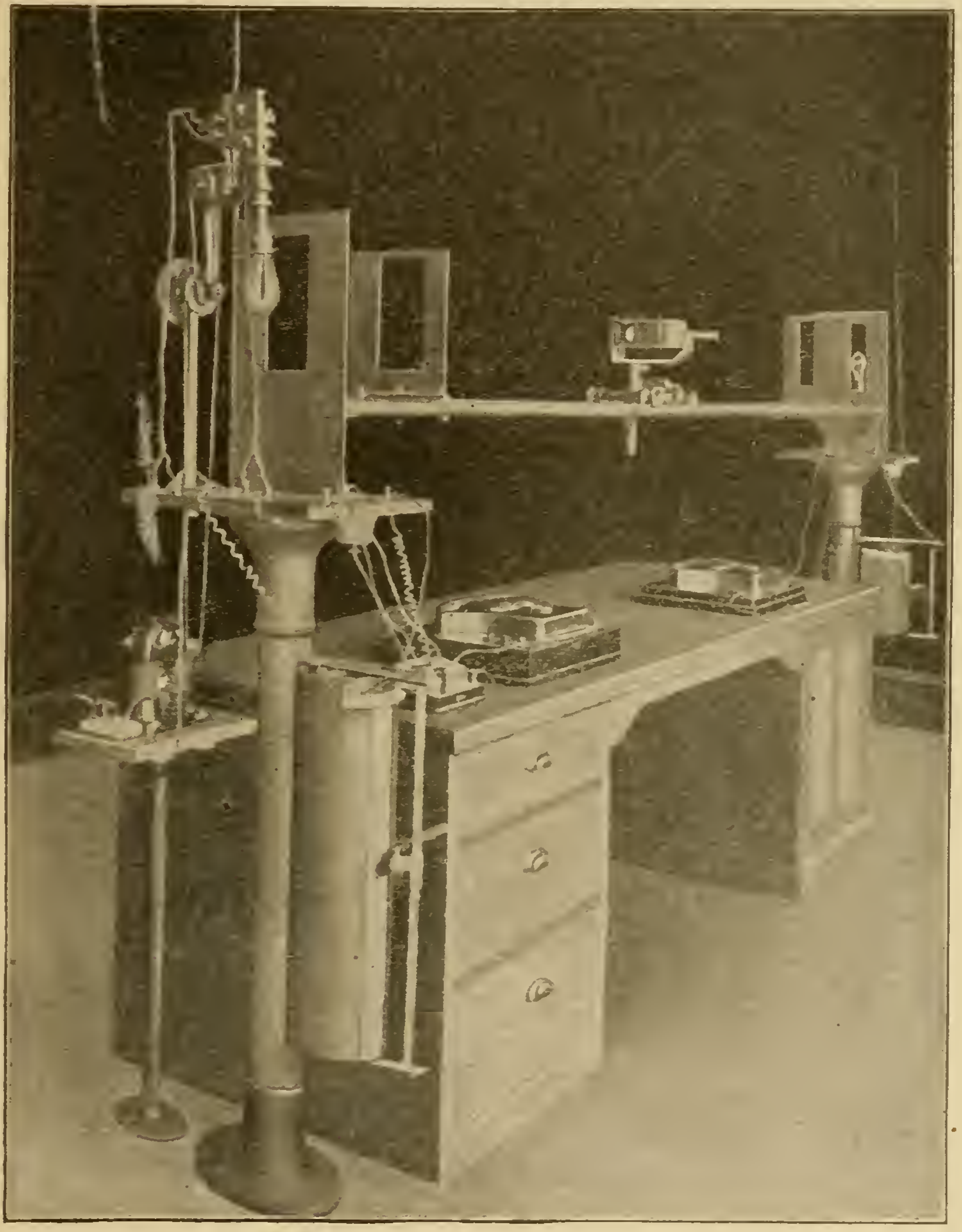


Fig. 55.

mean of the two readings serving as the true reading. This form of screen is used when especially accurate comparisons are required.

Fig. 55 shows a complete photometer with a Lummer-Brodhun screen, while Fig. 56 shows a Bunsen Screen and sight box.

In Fig. 55, the lamps are shaded by means of curtains so as to leave only a small opening toward the screen.

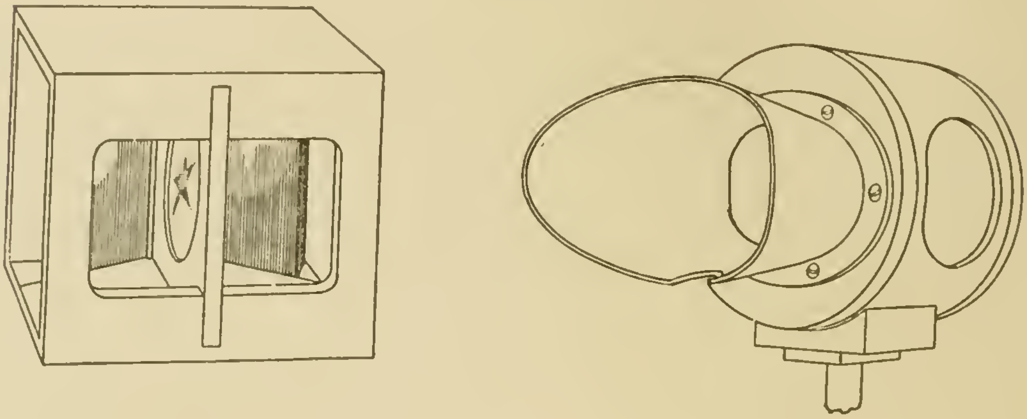


Fig. 56.

The Weber Photometer. As an example of a portable type of photometer, we have the Weber. This photometer, shown in Fig. 57, is very compact and is especially adapted to measuring intensity of illumination as well as the value of light sources; it may be used for exploring the illumination of rooms or the lighting of streets.

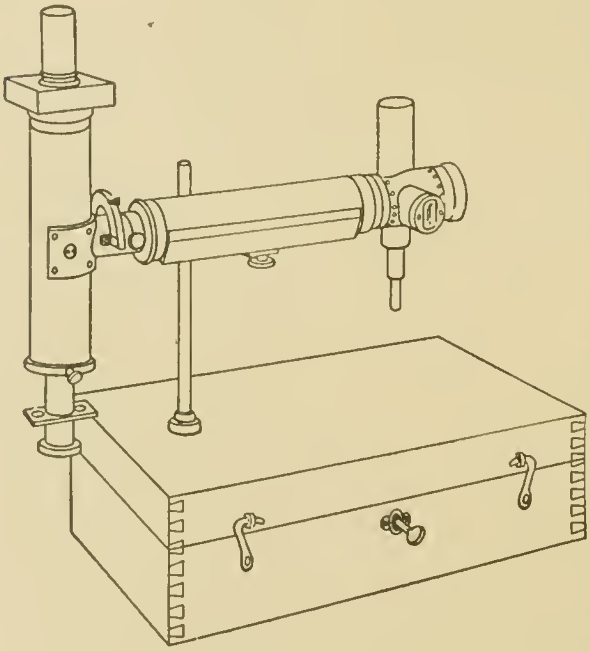


Fig. 57.

This apparatus consists of a tube A, Fig. 58, which is mounted horizontally and contains a circular, opal glass plate *f*, which is movable by means of a rack and pinion. To this screen is attached an index finger which moves over a scale attached to the outside of the tube. A lamp L, burning benzine, is mounted at the end of this tube. The benzine used should be as pure as possible, and the flame height should be carefully adjusted to 20 mm. when taking readings. At right angles to the tube A is mounted the tube B which contains an eye piece at O, a Lummer-Brodhun contrast prism at *p* and a support for opal or colored glass plates at *g*.

Operation. The tube B is turned toward the source of light to be measured, the distance from the light to the screen at *g* being noted. The light from this source is diffused by the screen at *g*, while that from the standard is diffused by the screen *f*. By moving the screen *f*, the light falling on either side of the prism *p* can be equalized. The value of the unknown source can be determined from the reading of the screen *f*, the photometer having previously been calibrated by means of a standard lamp in place of the one to be measured. The calibration may be plotted in the form of a curve or it may be denoted by a constant, C, when we have the formula,

$$I' = C \frac{L^2}{l^2}$$

C corresponds to a particular plate at *g*,

l = distance of screen *f* from the benzine lamp, and L = distance from the screen *g* to the light source being measured. Screens of different densities may be used at *g*, depending on the strength of the light source.

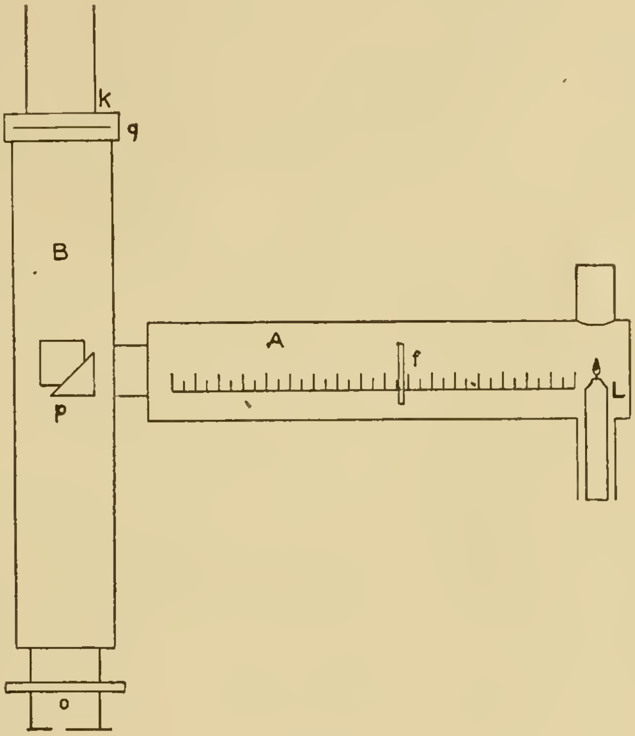


Fig. 58.

When used for measuring illumination, a white screen is used in connection with this photometer. The screen is mounted in front of the opening at *g*, and turned so that it is illuminated by the source being considered. Readings of the screen *f* are taken as before. A calibration curve is plotted for the instrument, using a known light source at known distance from the white screen when the instrument is mounted in a dark room.

A photometer, known as the **Matthews' Integrating Photometer,** has recently been placed on the market, and a very good idea

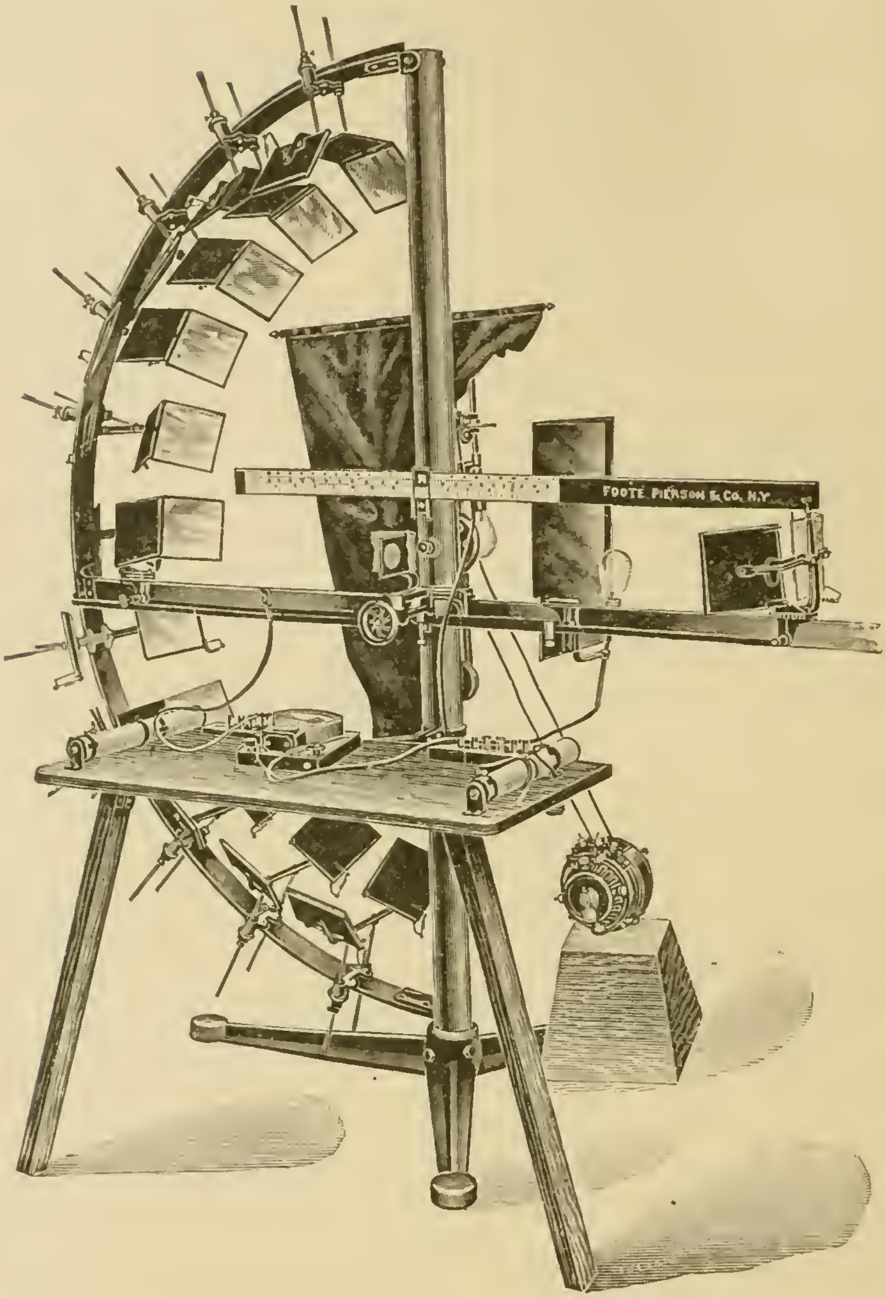


Fig. 59.

of its construction can be obtained from Fig. 59. By means of a system of mirrors, the light given by the lamp in several directions may be integrated and thrown on the photometer screen for comparison with the standard, the result giving the mean spherical candle-power from one reading. By covering all but one pair of screens, the light given in any one direction is easily determined.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

REINFORCED CONCRETE.

PART I

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1. How would you obtain testing samples from a carload of cement?

2. Why must kerosene or benzine be used instead of water in determining the specific gravity of cement?

3. While determining the specific gravity of cementby Le Chatelier's apparatus, it was observed that the introduction of 64 grams of cement increased the volume by 20.3 cubic centimeters. What was the specific gravity of the cement?

4. How many holes should there be in each square inch of a No. 100 sieve?

5. If a certain brand of cement requires 30 per cent of water to produce a paste of standard consistency, how much water should be used in a 1:3 mortar?

6. What is "initial set," how soon should it develop and what is the standard test for the time?

7. How much tensile strength should be developed by a briquette of neat Portland cement of good quality in 7 days? In 28 days?

8. Why does sand with grains of variable size produce a stronger concrete?

9. Why are cinders sometimes objectionable as an aggregate for concrete?

10. What general principles must be followed to obtain the densest concrete when using sand and stone of definite sizes? How would you determine the required proportions?

11. Assume that the voids in the sand are measured to be approximately 40 per cent and that the voids in the stone are approximately 45 per cent, using barrels containing 3.8 cubic feet of cement

how much cement, sand, and stone will be required for 100 cubic yards of 1 : 3 : 6 concrete?

12. What precautions should be taken to insure that hand-mixed concrete is properly mixed?

13. Under what conditions is it profitable to mix concrete by machinery?

14. What are the advantages and disadvantages of continuous mixers and batch mixers?

15. What are the practical difficulties and disadvantages, in the operation of automatic measuring machines, of measuring the materials of concrete?

16. Under what conditions is it proper to use "dry" concrete?

17. Why is "wet" concrete the proper grade to use for reinforced concrete work, especially when the reinforcing steel bars are numerous and complicated?

18. What is the danger in the excessive ramming of very wet concrete?

19. Why is there any practical difficulty in bonding old and new concrete? What measures are taken to obtain a good bond?

20. What is the effect of freezing of concrete before it is set? How can concrete be safely placed in freezing weather?

21. Describe one method of finishing a concrete surface so as to avoid any trace of the forms or centering.

22. Describe some of the methods of rendering concrete water tight.

23. What methods are used to prevent the forms or centering from adhering to the concrete?

24. What precautions are taken to prevent the lumber in the forms from swelling or buckling?

25. How long should the forms and centering for reinforced concrete remain in place under various conditions?

26. What general principle must be followed to obtain the maximum economy in designing the forms for reinforced concrete work?

REVIEW QUESTIONS

ON THE SUBJECT OF

REINFORCED CONCRETE.

PART II.

1. Why is there but little if any structural value to a beam made of plain concrete?

2. State briefly the fundamental reasons for the economy of using concrete for compressive stresses and steel for tensile stresses.

3. What is meant by the "neutral axis" of a beam?

4. What is the essential difference between the elasticity of concrete under compression and that of steel or wood?

5. Develop the formula (equation 3) for the summation of the compressive forces in a concrete beam, employing your own language altogether and elaborating in detail every step in the line of argument.

6. What is the value of k when using 1 per cent of steel in beams made of 1:3:6 concrete?

7. What is the practical effect of using a lower percentage of steel than that called for by the theory (equation 10)? Is there any economy in using less steel?

8. What is the practical effect of using more steel than the theory calls for? Does it make the structure any stronger?

9. Develop a series of equations (similar to equation 13) on the basis of 1:2:5 concrete whose modulus of elasticity (E_c) is assumed at 2,650,000 and whose ultimate crushing strength (c') is assumed at 2,400 lbs.

10. Using a factor of 2 for dead load and a factor of 4 for live load what is the maximum permissible live load which may be carried on a slab with a total actual thickness of 6 inches and a span of 8 feet?

11. If a roof slab is to be made of 1:3:6 concrete and designed to carry a live load of 40 pounds per square foot on a span of 10 feet, what should be the thickness of the slab and the spacing of $\frac{3}{8}$-inch square bars?

12. If a floor slab panel is 25 feet 6 inches wide (perpendicular to the direction of the main reinforcing bars) and the calculation shows that $\frac{1}{2}$-inch bars should be spaced $6\frac{3}{4}$ inches apart, how would you instruct the workmen about spacing the bars in such a panel?

13. A beam having a span of 18 feet is required to carry a live load of 12,000 pounds uniformly distributed. Using 1:3:6 concrete and a factor of four what should be the dimensions of the beam whose depth is approximately twice its width?

14. What will be the intensity per square inch of the maximum vertical shear in the above beam?

15. What are the two general methods of providing for diagonal shear near the ends of the beam?

16. Make a drawing of the beam designed in Question 13 showing especially the reinforcement and the method of providing for the diagonal shear.

17. Discuss the advantage of using steel with a high elastic limit and also the possible danger in such use.

18. Make a design for a slab of 1:3:6 concrete, reinforced in both directions which is laid on I-beams spaced 10 feet apart in each direction.

19. What will be the bursting stress per inch of height at the bottom of a concrete tank having an inside diameter of 10 feet designed to hold water with a depth of 40 feet? What size and spacing of bars will furnish such a reinforcement?

20. With a nominal wind pressure of 50 pounds per square foot, on a flat surface, what will be the intensity of the compression on the leeward side of the tank, allowing also for the weight of the concrete, and assuming a thickness of 12 inches?

21. On the basis of the approximate theory given in the text, what would be the required steel vertical reinforcement for the above described tank?

22. Design a retaining wall to hold up an embankment 30 feet high, making a cross-sectional drawing and plan drawing similar to Fig. 48, assuming that the buttresses are to be 15 feet apart.

23. Compute the required detail dimensions and the reinforcement for the box culvert, illustrated in Fig. 49, on the basis that the culvert is to be 10 feet wide, 12 feet high, supporting an embankment

REVIEW QUESTIONS

ON THE SUBJECT OF

STEAM AND HOT WATER FITTING.

1. What points should be borne in mind when selecting a heating boiler for a given service?

2. Explain by an example how to check the catalogue rating of a boiler.

3. Point out the difference between (a) direct, (b) direct-indirect, and (c) indirect radiation.

4. State the advantages of each type.

5. What advantages do overhead coils possess over other classes of direct radiation?

6. (a) With overhead coil heating, how should the coils be placed with reference to walls and floor to secure the best results? (b) Why?

7. In what two ways is heat given off by a radiator?

8. What advantages has a wet return system over one with dry returns?

9. (a) In what classes of buildings, as a rule, may the overhead feed system be used and why? (b) What advantages are possessed over the up-feed system?

10. When should a two-pipe system be used in preference to a one-pipe?

11. Explain the action of a siphon trap in balancing a low pressure steam heating system.

12. When is it advisable to establish an artificial water line?

13. Explain in detail how to compute the radiating surface for low pressure steam in a corner room 18 ft. square, 10 ft. high, the exposed wall to be 16 in. thick, exposed toward the north and

west, and having glass surface equal to one-fourth the total exposed surface of wall and glass combined.

14. Describe the action of aspirating heaters. To be most effective in causing a rapid flow of air in a flue, at what point should they be placed?

15. State some advantages to be secured by exhaust steam heating.

16. What appliances are necessary in connection with exhaust steam heating that are not used with ordinary low pressure heating?

17. (a) What are the main features in the so-called Vapor System? (b) What advantages are claimed over ordinary steam heating systems?

18. What is the purpose of the "mercury-seal" in that type of heating system?

19. State the purpose and explain the action of steam traps.

20. What is meant by "absolute pressure" of steam?

21. If a pipe is 80 ft. long when filled with steam at 10.3 pounds pressure, what will be its length when filled with steam at 100.3 pounds? Show method of computation.

22. Describe (with sketches) several methods for taking up expansion.

23. What is meant by the term "O. D." pipe?

24. What is the minimum thickness of "O. D." pipe to permit threading?

25. (a) With low pressure piping, up to what size is it advisable to use screwed fittings? (b) What advantages are there in using flanged fittings for the larger sizes?

26. Describe two types of air valves.

27. (a) Mention two kinds of dies.

(b) What points must be attended to in order to secure the best results in using them?

28. What advantages have pipe tongs over wrenches?

29. What advantages are possessed by the overhead feed system of hot water heating over the up-feed system?

30. What precautions is it necessary to take with regard to expansion tank connections and why?

31. State some advantages claimed for (a) open tank (b) closed tank hot-water heating systems.

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC WIRING

1. Explain the three-wire system of wiring.

2. In case a test shows excessive leakage, or a ground or short circuit, how would you locate the trouble and remedy it?

3. Describe the construction and use of outlet-boxes.

4. What is the principal difference between alternating and direct-current circuits, so far as concerns the wiring system?

5. Compare the advantages of the two-wire and three-wire systems of wiring.

6. Under what general heads are approved methods of wiring classified?

7. A single-phase induction motor is to be supplied with 25 amperes at 220 volts; alternations 12,000 per minute; power factor .8. The transformer is 200 feet from the motor, the line consisting of No. 4 wire, 9 inches between centers of conductors. The transformer reduces in the ratio $\frac{2,500}{250}$, has a capacity of 30 amperes at 220 volts, and, when delivering this current and voltage, has a resistance-E. M. F. of 2.5 per cent, and a reactance E. M. F. of 5 per cent. Calculate the drop. (Use table and chart.)

8. What are the distinctive features of the different kinds of metal conduit?

9. Suppose power to be delivered, 300 K. W.; E. M. F. to be delivered, 2,200 volts; distance of transmission, 15,000 feet; size of wire, No. 00; distance between wires, 24 inches; power factor of load, .7; frequency, 100 cycles per second. Calculate line loss and drop in per cent of E. M. F. delivered. (Use table and chart.)

10. In installing A. C. circuits, what requirements are insisted on as to the placing of conductors in conduits?

11. Describe the manufacture, use, and special advantages of the different kinds of armored cable.

12. Describe three different methods of testing? Which is to be preferred?

13. What conditions determine whether a two-wire or three-wire system of wiring should be used?

14. In locating cut-out cabinets and distributing centers, what requirements should be fulfilled?

15. What is "knob and tube" wiring? Explain its use and discuss its advantages or disadvantages.

16. How far apart should insulators be placed?

17. What tests should be made before an electric wiring equipment is finally passed for acceptance? Give reasons.

18. What regulations govern the use of fibrous tubing?

19. What is meant by mutual induction?

20. What are the advantages and disadvantages of overhead linework as compared with underground linework?

21. Describe and illustrate by sketches proper methods of supporting and protecting conductors.

22. Discuss the advantages of running conductors exposed on insulators.

23. Illustrate by diagram, proper and improper methods of grouping conductors of two two-wire circuits.

24. What dangers are inherent in the use of moulding? What precautions should be taken to avoid them?

25. Describe the proper methods of laying out branch circuits, (*a*) in fireproof buildings; (*b*) in wooden frame buildings. Give sketches.

26. What methods of installing wiring are best adapted for the following classes of buildings, (*a*) fireproof structures; (*b*) mills, factories, etc.; (*c*) finished buildings; (*d*) wooden frame buildings?

27. What is skin effect? Its bearing on the problem of wiring?

28. In selecting runways for mains and feeders, what precautions should be taken?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC LIGHTING.

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1 State the current, voltage, candle-power, and efficiency of the incandescent lamp most commonly used.

2. What do you understand by the "smashing point"?

3. Give the main points of difference between the three forms of arc lamp mechanism.

4. Mention the three principal parts of the Nernst lamp.

5. Describe with sketch the anti-parallel system of feeding.

6. Prove the law that illumination varies inversely with the distance.

7. Why is arc light photometry a more difficult problem than incandescent?

8. Calculate the illumination three feet above the floor at the center of a room 18 feet square and 12 feet high, lighted by four 10-candle-power lamps 9 feet above the floor at the center of the side walls, assuming the coefficient of reflection to be 50%.

9. What material is used for the filament of incandescent lamps? Explain why.

10. From the curve given in Fig. 4, determine the efficiency which corresponds to the temperature of 1300° Centigrade.

11. What is the object of double carbons in an arc lamp?

12. What is meant by mean spherical candle-power?

13. What is the function of the heater in the Nernst lamp?

14. Describe the Bunsen Photometer.

15. How does the lighting of public halls differ from that of residences?

16. Why cannot platinum wire be used for the filament of incandescent lamps?

17. In a direct-current arc lamp, which carbon burns away the more rapidly?

18. How are arc lamps rated?

19. What are the important advantages of the two-wire parallel system of distribution?

20. Name and describe the most desirable standard for photometric measurements.

21. How many measurements should be taken in the determination of spherical intensity?

22. What is meant by flashing? Explain.

23. Define emissivity.

24. If the voltage of an incandescent lamp be increased 4% above normal, what is the effect on the candle-power, efficiency and light?

25. Explain the Cooper-Hewitt lamp, stating the two methods of starting.

26. Compare the open and enclosed arc lamps.

27. Why is the positive carbon placed above the negative in a direct-current arc lamp?

28. Sketch and name the different forms of incandescent lamp filaments.

29. Under what conditions can a 3.1-watt incandescent lamp be used?

30. What is the function of the arc lamp mechanism?

31. What are the advantages of the three-wire system?

32. Why is it necessary to exhaust the bulb of an incandescent lamp?

33. At what point in their life should incandescent lamps be replaced?

34. What is the object of a resistance in series with the arc lamp in constant-potential direct-current systems?

35. Name the advantages of the Nernst lamp.

36. What sort of lamps and of what candle-power should be used in residence lighting?

37. Give the characteristics of the Cooper-Hewitt lamp.

38. What will be the external resistance on a 110 volt constant-potential system, if the load consists of 437 lamps of 16 candle-power?